VOL. 2

United States of America, }
Northern District of Illinois, } ss.
Eastern Division. }

IN THE

District Court of the United States

UNITED STATES OF AMERICA, *Complainant*, vs. THE SANITARY DISTRICT OF CHICAGO, *Defendant*.	C. C. No. 29,019, and Equity No. 114.

RECORD OF TESTIMONY AND PROOF TAKEN BEFORE COMMISSIONERS APPOINTED TO TAKE TESTIMONY IN SAID CAUSE.

Appearances:

Mr. James H. Wilkerson,
United States Attorney, and
Mr. Albert L. Hopkins,
Assistant United States Attorney,
For Complainant.
Mr. Edmund D. Adcock and
Mr. Alfred S. Austrian,
For Respondent.

1914
THE GUNTHORP-WARREN PRINTING COMPANY
CHICAGO

VOL. II.

INDEX TO WITNESSES.

1913.

Defendant's.

ERRATA

CORRECTIONS TO GARDNER S. WILLIAMS' TESTIMONY.

Page	Line		For	read
575	3, 7, 15	For	Couteau	read Coteau
576	16		Millwright	Mill site
576	31		Case	Amount
578	8		Sewerage	Sewage
589	11		Increment	Increments
598	1		Lopesch	Aux Peche
598	24		Plan	Plane
602	38		Eough	Enough
609	4		Within average	Within an average
609	29		1909	1899
610	29		Gages	Gagings
612	9		Velocity	Discharge
616	29		Junior, Engineer	Junior Engineer
626	39		2.22	2.209
627	27		.79	.78
629	9, 11		Resistancies	Resistances
631	9		Represent	Represents
631	30		28872	28758
631	35		28872	28758
631	35		1617	1610
631	37		1617	1610
631	37		190681	190674
631	41		910	917
632	28		9.06	904
634	7		570.79	570.69
635	30, 31		Made 1896	Made in 1896
638	37		24436	24458
638	38		24436	24458
638	44		27861	28059
639	17		27861	28059
641	7		575,174	575,175
642	5		presented	presents
642	5		table 17 differences	Table 17, differences
642	22		581.56	581.57
642	25		8.71	8.72
643	18		raise	rise
643	44		27861	28059
645	39, 40		** of a foot. By Tables **	. . . . . of a foot, by Tables
647	25		12995	13005
647	31		12995	13005
647	42		divide	divided
648	20		196908	196907
648	32		12995	13005
649	12		12995	13005
649	12		8664	8670
649	14		8664	8670
649	14		27523	27517
649	17		27523	27517
650	34		12995	13005
650	35		24620	24613
656	45		15820	16036
657	2		0.507	0.508
657	3		31203	31370
658	4		14638	14609
658	7		0.507	0.508
658	8		28872	28758
661	34		26	36

CORRECTIONS TO GARDNER S. WILLIAMS' TESTIMONY.

Page	Line	For	read
662	26	when	whence
662	28	11389	11253
662	32	.268	.368
662	33	30948	30579
662	33	five	eight
663	29	10417	10281
663	33	.0368	0.368
663	34	28307	27938
663	35	575	820
663	45	28872	28758
664	8	28872	28758
664	13	40442	40328
664	18	40442	40328
664	38	191023	191614
664	40	197633	198002
670	4	248721	248908
670	15	197633	198002
670	16	98.8	99.0
670	20	0.988	0.99
670	20	0.85	0.855
670	21	29600	29780
670	31	29600	29780
670	33	29600	29780
672	16	27336	26155
672	37	28359	33142
672	38	32060	30460
680	42	240820	240818
681	4	196739	196729
681	11	196739	196729
681	12	196739	196729
681	14	196739	196729
681	14	41781	41791
681	33	41781	41791
681	35	4720	4730
681	38	35.78	35.76
681	43	35.78	35.76
682	6	4720	4730
682	6	14430	14420
682	14	196739	196729
682	17	196739	196729
682	23	10252	10242
682	24	199039	199029
682	38	10252	10242
682	39	9743	9753
683	7	9743	9753
683	10	35793	35803
685	19	correct	corrected
685	20	nearly	over
689	13	an excess	a deficit
689	19	35.06	35.32
689	19	34.13	34.90
689	20	0.93	0.42
689	40	28872	28758
689	42	0.366	0.368
690	2	28872	28758
690	2	30600	30483
690	3	30600	30483
690	3	197633	198002
690	9	15.6	15.4
690	22	34000	35000

CORRECTIONS TO GARDNER S. WILLIAMS' TESTIMONY.

Page	Line			
690	25	For 34000		read 35000
690	25	.34		.33
690	30	34000		35000
690	30	17000		17850
690	32	30600		30480
690	33	13600		12630
692	15	30332		31918
692	18	0.33		0.31
692	19	0.33		0.31
692	19	0.61		0.63
692	20	0.61		0.63
692	21	30322		31918
692	21	18000		20000
694	26	28872		27938
694	30	28872		27938
694	30	45600		45900
705	23	Huran		Huron
707	2	Seven-eighths percent		Seven-eighths
707	27	197633		198002
707	31	197633		198002
707	31	172500		174000
707	38	25000		24000
707	40	10.4		10.0
708	1	25300		25200
710	27	is		observations
710	28	were		was
710	28	is, were		it was
712	33	28872		27938
712	34	32300		31300
724	13	LXIX-a		LIX-a
724	37	LXIX-c		LIX-c
724	42	LXIX-d		LIX-d
724	44	LXIX-e		LIX-e
725	1	LXIX-f		LIX-f
819	25	136		144.6
819	36	136		144.6
819	37	136		144.6
859	July 20th	1st Column	for 0.23	read 0.26
		3rd Column	0.46	read 0.49
	July 25th	2nd Column	0.12	read 0.28
		3rd Column	0.47	read 0.63
860	Aug. 2nd	2nd Column	0.85	read 0.35
		3rd Column	1.17	read 0.67
	Aug. 11th	2nd Column	0.21	read 0.22
		3rd Column	0.44	read 0.45
	Aug. 26th	1st Column	0.58	read 0.60
		3rd Column	1.08	read 1.10
	Aug. 31	3rd Column	0.25	read 0.28
873	Line 40	gravity. The		gravity, the
888	Line 35	1898		1908
889	Line 22	571.96		571.94
889	Line 24	571.96		571.94
889	Line 24	573.26		573.24
898	Line 18	three		two
920	Line 35	1899		1889
953	Line 43	enough		through
988	Line 7	considered		to consider

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IN THE

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UNITED STATES OF AMERICA, *Complainant*,		
vs.	}	C. C. No. 29,019.
THE SANITARY DISTRICT OF CHICAGO, *Defendant*,		

Depositions taken pursuant to stipulation of counsel for the respective parties, statutory notice being duly waived, at the Hotel Netherlands, New York City, on March 18, 1913, and on subsequent dates.

Appearances:

Mr. Wilkerson, representing the Government.

Mr. Adcock and Mr. Austrian, representing the Sanitary District.

All objections to questions, answers and exhibits shall be considered as having been made except as to questions involving form, and secondary evidence.

GARDNER S. WILLIAMS, a witness called on behalf of the Sanitary District, was first duly sworn by the Commissioner, and testifies as follows:

Direct Examination by Mr. Adcock.

Q. Will you state your full name?
A. Gardner S. Williams.
Q. Where do you live?
A. Ann Arbor, Michigan.
Q. Your place of business?
A. Ann Arbor, Michigan.
Q. What is your business?
A. Civil engineer.
Q. Are you a member of any societies of civil engineers?
A. I am a member of the American Society of Civil Engineers, and a member of the American Institute of Consulting Engineers; member of the Detroit Engineering Society; American Water Works Association; New England Water Works Association, and some other less important societies.
Q. Where did you take your early training?
A. I was graduated as Bachelor of Science in Civil Engineering from the University of Michigan in 1889.
Q. Have you had any experience in the hydraulics and hydrography of the Great Lakes, and studies of these subjects?
A. I have been interested in and connected with the study of hydraulics and hydrography of the Great Lakes since I became the civil engineer of the Board of Water Commissioners of Detroit in 1893. In fact prior to that, I was considerably interested in the problems of navigation and hydraulics on the Great Lakes from the standpoint at that time of the student, not having any official connection with it in any way. But I was at that time familiar with the discussions of the effects upon lake levels of various changes that were under contemplation at that time.
A. After you graduated from college in 1889, what did you do?
A. After graduation, I was located at Owosso, Michigan, in charge of water works construction for the season. Then I was with the Russel Wheel and Foundry Company in Detroit as engineer until 1893, when I went with the Board of Water Commissioners of Detroit as civil engineer to the

Board. I remained there until the fall of 1898 when I went to Cornell University and became Professor of Experimental Hydraulics, and Engineer in charge of the Hydraulic Laboratory.

I remained there until 1904 when I came to the University of Michigan as Professor of Civil, Hydraulic and Sanitary Engineering, which position I held until October 1, 1911, when I resigned, and since that time I have been engaged entirely in consulting practice.

Q. What general experience have you had, Mr. Williams, as an engineer, and with what projects have you been connected, in a general way?

A. I started with the water works construction at Bismarck, Dakota; then at Greenville, Michigan, and Owosso, Michigan; then with the Detroit Board of Water Commissioners, in which latter position I began consulting work.

I was the consulting engineer to the Ithaca Water Works Company, or Water Works construction, construction of purification plants, etc. While located at Cornell I was consulting engineer to the Michigan-Lake Superior Power Company on hydraulic installations for their power plant at Sault St. Marie; also upon discharge measurements of the St. Marys River, which were undertaken by them in about 1899 or 1900.

I was consulting engineer to the Edison Sault Electric Company and the Chandler-Dunbar Water Power Company, and as such designed and supervised the construction of the power plant in the Rapids at Sault St. Marie.

I was consulting engineer for the Eastern Michigan Edison Company on water power developments on the Huron River. I designed and supervised the construction and the overhauling of several water power plants. I designed and constructed a water power plant on the St. Joseph River, Michigan, for the City of Sturgis. I was consulting engineer to the United States Corps of Engineers on the substructure of the power house in connection with the lock and dam of the Mississippi River improvement between Minneapolis and St. Paul.

I was consulting engineer to the Canadian Light & Power Company in connection with power development and incidental improvements to navigation on the Couteau and Cedar Rapids of the St. Lawrence River near Montreal.

I was employed to advise the Central Colorado Power Company on the construction of certain dams and their effect upon the channels of some of the rivers in the vicinity of

Colorado Springs, particularly as to effects of floods. I have had meanwhile engagements in numerous other places, but I think those are the principal ones.

Q. Have you held any official position in societies of civil engineers?

A. I was a director of the American Society of Civil Engineers for one term, for a term of three years, which I think expired in 1910, I will not be certain.

I have been, for five years I believe, the chairman of the Board of Managers of the Association of Engineering Societies, which is composed of societies in Boston, St. Louis, Detroit, San Francisco, Milwaukee, New Orleans, and several other cities; the purpose being to provide for the publication of the papers and discussions that are presented before the Society.

Q. Are you connected with any publication relating to civil engineering?

A. Well, the Journal of the Association of Engineering Societies was published by the Board of Managers, of which I am the Chairman.

Q. Outside of your business connections have you made any special studies or presented any papers in conntion with the hydraulics, hydraulic engineering and sanitary conditions, etc.?

A. I presented a paper before a sanitary convention in Detroit, in 1897, I think, upon the transmission of typhoid fever from Port Huron to Detroit through the channels of the St. Clair River and through Lake St. Clair, which involved of course a considerable study of the hydraulics of that section of the connecting waters of the Great Lakes.

I presented a paper to the American Society of Civil Engineers, which was published in 1902, I believe, upon experimental investigations upon the flow of water in pipes. And I have contributed to numerous discussions at one time and another on hydraulic and sanitary subjects. Those are the two principal ones.

Q. In connection with your engagements at Cornell University and the University of Michigan in the capacities which you have mentioned, what was the scope of the work there, and what studies did that cover?

A. The engagement at Cornell placed me in charge of the first, in fact the only large experimental hydraulic laboratory that has ever been constructed; in fact the largest that there has been in the world. The scope of investigations that were

carried on there, during my connection with it, involved first some investigations upon the flow of water in pipes, but more particularly investigations of the methods of measuring water in open streams, open channels.

Experiments were made upon the measurement of water over weirs by means of floats, and by means of current meters. And this work was carried on during the entire period of my residence there, which was substantially six years.

Q. When you speak of measurement of water by means of weirs and floats and current meters, will you explain just what those terms mean?

A. The measurement of water may be accomplished in a variety of ways. The most accurate method of course is to measure it by the weight that is delivered or involved. That of course is limited to comparatively small quantities of water.

The next method in accuracy is the measurement by volume, which may be done in considerable quantities in reservoirs and large basins, where the area of the surface is known and the rise of the water can be measured.

The next method in accuracy as ordinarily accepted, and as I believe it to rank, is the measurement over a weir. A weir is another term for a dam, but in this country it is ordinarily applied to a dam which is used for the measurement of water.

Extensive and elaborate studies have been made to determine the quantity of water which will pass over a weir or partition in a channel of known height and form for different heights of water above the crest or top of the dam or partition.

The most extensive series of experiments upon the flow of weirs on record are those made by the French engineer Henri Bazin at Dijon in France, from about 1886 to about 1889. In these investigations, the quantity of water that was measured over the weir, or that was passed over the weir was measured volumetrically in a basin which was composed of a part of a canal.

In America the first extensive investigations and perhaps the best known ones were made by Mr. James B. Francis at Lowell, about 1850. The volume of water handled by Mr. Francis was very much greater than had ever been attempted by anybody else, and was greater than was handled by Bazin.

The experiments which have the largest scope in the measurement of water over weirs of any that have ever been made

were made by Messrs. Fteley, Mr. Alphonse Fteley, who is now deceased, and Mr. Frederick P. Stearns of Boston, which were made in connection with the Boston Water Supply for the purpose of determining the quantity of water that was supplied from the Sudbury aqueduct which furnished the water to the City of Boston. The quantity of water measured in that case far exceeds anything that has been volumetrically measured anywhere in the world to date.

The investigations at Cornell did not involve volumetric measurements except in the instance of small quantities, but were based upon the comparison of two measuring devices; that is two weirs so situated that the water which passed over one would be passed over the other, and so that the conditions at the two weirs were markedly different, one of them being very large, that is nearly twice as high as the other, so that the water approached it with very much less velocity than it approached the other, and by comparing the discharges over these two, according to formulae which were derived from a study of the experiments of Bazin, Francis and Fteley and Stearns. These measurements of water over weirs were also compared simultaneously with measurements by means of rod floats and current meters.

The rod float is simply a weighted rod, which is so weighted and balanced that it will float with its top just above the water, and stand in a vertical position.

Q. Where is the bottom of it?

A. And the bottom of the float is made to pass near to the bottom of the channel.

In the experiments at Cornell, we had a perfectly smooth channel with vertical sides and we experimented with floats of different depths, ranging from a depth of 1/10 of the depth of the water down to about 98 per cent. of the depth, and compared the discharge so obtained with the discharge as indicated simultaneously by the weirs at the upper and lower ends of the channel. At the same time or at other times, measurements were made in the ordinary way with current meters which were located at various points along the canal between the two weirs, and in that way a comparison of the relative accuracy of the several methods was obtained.

Q. Will you describe the current meter as it is ordinarily used, as the term is used?

A. The current meter consists essentially of a revolving piece of apparatus, which is caused to revolve by the motion of the current when the meter itself is held still in it, or when

it is moved by an external force through the water. It also is furnished with a tail or vane which so directs it that if left free to assume its normal position it will point directly against the current. It is usually pivoted both in the horizontal plane and in the vertical plane, so that it is free to revolve in both directions, and assume the position in which the current is moving.

The revolutions of the wheel are caused to make and break an electric circuit, which are repeated in a sounding device that is held by the observer, ordinarily a small telephone which is simply fastened to its head, and at each revolution of the wheel there is a click so that he is able to count the revolutions of the wheel and at the same time with a watch thereby determine the number of revolutions that take place in any unit of time that is desired.

In transferring the revolutions to velocity of water, it is necessary to have the meter rated; that is to know how many revolutions per minute represent, say, a foot of velocity. That is ordinarily done by dragging the meter at known rates through still water, and recording the revolutions for the distance passed through in a given time, it being assumed that the velocity of the meter in still water has the same effect in creating rotation that the velocity of water past the still meter would have in creating rotation. That process of dragging the meter in still water and determining the revolutions which correspond to a velocity of translation through the water is called rating.

The meter as operated in small channels where it can be done, is ordinarily held upon a rigid staff, when both its direction and position can be very accurately determined. In working in deep channels, it is necessary to suspend the meter on a cable, in which case its direction cannot be determined with the ordinary meter and its position is more or less influenced by the necessary curvature of the lines, due to the effects of the current. To overcome the former objection, a current meter has been devised for that, which is known as the direction current meter, in which there is a magnetic needle that transmits its position electrically to what is known as a repeater at the surface, which indicates on the surface the position in horizontal direction which the current meter occupies, so that it is possible with that device to tell so far as the horizontal plane is concerned in what direction the meter is pointing; but with an ordinary meter it is not pos-

sible to determine that, unless the meter is within the range of vision through the water.

Q. When you speak of ordinary meter, what make of meters do you refer to?

A. Well, when I say "ordinary meter" I refer to all except those equipped with the direction meter device, which is only used in connection with the so-called Ritchie-Haskell direction current meter.

Q. What period of years did your investigations and work at Cornell cover?

A. About 1899, from early in 1899 or the fall of 1898 until 1904.

Q. What was the scope of your work at the University of Michigan?

A. At the University of Michigan, my work so far as that connected with the University was concerned, was mainly in the teaching of the subjects indicated by the title of my chair.

At that time I was engaged upon numerous investigations involving the measurement of water, the flow of water; made several investigations of the quantity of water flowing over various structures as dams, under particular conditions; that is the effect of various forms of crests and so on upon the low discharge of such structures, with a view of being able to determine more accurately the quantity of water that was flowing in rivers where such structures were in use, in connection with measurements of run-off of streams.

Q. During the time that you were at Cornell, and also at Michigan, were you engaged in any way in connection with your business as consulting engineer as you are carrying it on now?

A. Yes, all the time I was at Cornell, and even before that, and all the time I was at Michigan I was engaged as consulting engineer, maintaining a regular office and devoting probably from one-third to one-half of my time to my outside practice.

Q. Did the construction of the plants and your work in connection with that have anything to do with navigable waters?

A. The construction work at the Sault St. Marie was in what was assumed to be navigable water in that the War Department of the United States exercised control over the structures which were put there, and such structures could only be erected upon a permit from the Secretary of War.

The constructions with which I was connected at Detroit for the Board of Water Commissioners, which involved matters of intakes in the Detroit River, and for which I made extensive surveys both with regard to the hydrography and character of the bottom and so on of portions of the Detroit River and also Lake St. Clair; and as to the temperatures of the water at different places in the river; and also as to the currents which incidentally involved a considerable amount of current meter work, were all carried on in navigable waters, and subject to the interruptions of navigation. The work of gauging the St. Mary's River which was attempted by the Michigan-Lake Superior Power Company, under my direction, was also carried on in the navigable water of the river above the locks, at a point where vessels were passing, several every hour.

Q. What year was that?

A. Those measurements were made during the summer of 1900, I believe.

Q. Did you make any further measurements on the flow of the St. Mary's River subsequently to that time, or have you made any special studies in that regard?

A. I made no measurements subsequent to that time, but I made a very careful study of the records of flow and the conditions of flow in connection with the development of the water power in the Rapids for the Edison Sault Electric Company; and also in connection with the problems which were introduced in a suit between the United States Government and the Chandler-Dunbar Water Power Company and the Edison Sault Electric Company and others, for the purpose of condemning the property of the aforesaid companies. The general problem of the hydraulics of that part of the river was I think quite carefully considered.

Q. Have you made any study of measurements of the flow of the St. Clair River; and if so, what time did they cover?

A. I have made a very careful study of the flow of the St. Clair River. You mean a study of the measurements.

Q. Study and measurements both?

A. The measurements on the St. Clair River, the early measurements, date back to the early sixties, 1864, I believe, when discharge measurements were made under the old Lake Survey organization, at which time the current meter as it is now known was really developed, the first use of the telegraphic current meter, so-called, that is when the electric

device was made, at that time, in discharge measurement of either the St. Clair or the St. Mary's River or both, as both were gauged about that time.

The next work that was done on the St. Clair River so far as is known to me—and I have searched the records with some diligence—was in 1899 when the present Lake Survey organization took up the problem of measuring the discharge; and those measurements which were continued through 1902 and latterly taken up again in 1908 and carried on through 1910 have in the main been incorporated in the data already presented in this case. My study of those measurements began about with the inception of this case, although I had a general knowledge of them prior to that time; and had discussed them with various engineers of my acquaintance who were interested in them.

Q. Take the Detroit River, I will ask you the same question.

A. The gaugings of the Detroit River were made in 1901-2 at a section in the vicinity of Fort Wayne below the City of Detroit, and the results of these gaugings were published in the report to the Chief of Engineers for 1903, I believe. The work which I did myself on the Detroit River involved the gauging of the American channel through the ice in the winter of 1896 I think, or possibly January, 1897. There were also several gaugings of the Detroit River in the vicinity of Amherstburg made during 1908, 1909. I am in doubt about 1908. I think they were made in 1909 and more in 1912, in which measurements were made of the several channels, during the construction of the so-called Livingstone Channel, and after the opening of the channel. Those gaugings were made by the United States Government through the River Improvement office at Detroit; the work being in charge of Mr. Charles Y. Dixon, Assistant Engineer in charge of the work in the Lower Detroit River.

Q. What have you had to do with the measurements or consideration of the flow of the St. Lawrence River, and during what period did that cover?

A. The St. Lawrence River was gauged in 1900 and 1901, and there have been gaugings within the past two years I believe.

The data of the 1900-1901 measurements have been utilized in the preparation of exhibits for this case. My individual study of those measurements began at the time that this case was opened. Succeeding that I had occasion to be associated

with the gauging of the St. Lawrence River at a point considerably lower down, being at the bridge across the river just above the Couteau Rapids. This work was done for the Canadian Light & Power Company of Montreal, in connection with the proposed power development and navigation improvements which they were contemplating through the Couteau and Cedar Rapids; and the work was in charge directly of Mr. Murray Blanchard, who was formerly an assistant engineer or junior engineer in the United States Lake Survey service, and was an assistant upon the work on the St. Clair River during the first three years and in charge of it during 1902, and then was in immediate charge of the measurements on the Detroit River in 1901 and 1902.

These gaugings were also supplemented by gaugings of individual channels in the Couteau Rapids, carried out by the same organization.

Q. Have you made any study or investigations concerning the Lake levels and the relation of the levels of the different lakes to each other, with reference to run-off and rainfall, etc., and if you have state what investigations you have made, and what studies you have made?

A. The subject of the discharge of the Great Lakes, in its various phases, has been one that has attracted my attention for a good many years, and I have made, I think, a very careful study of the elevations of the lake, the discharge of the lakes as indicated by such measurements as have been made, the effects of rainfall so far as those effects can be determined, or so far as I have been able to determine them from such records as are available in the files of the United States Weather Bureau, Smithsonian Institution, War Department, and from various other sources, as for instance some State observations and so on.

Q. Are those the recognized sources of information that you refer to, the War Department, Smithsonian Institution, etc.?

A. United States Weather Bureau. They are the best, and I may say the only reliable sources of information that are known to me; and other records are to be found in Government publications.

Q. If there were other sources, would you be likely to know them?

A. I think I would.

Q. Have you made any investigations or studies of hy-

draulics or sanitary problems, in connection with any litigation in which you have been engaged?

A. Yes, I was one of the witnesses retained by the City of St. Louis in the State of Missouri, in the case of the State of Missouri *vs.* The State of Illinois and the Sanitary District of Chicago, before the United States Supreme Court, being what is ordinarily known as the Drainage Canal case. My investigations there had particularly to do with the sanitary phases of the case, and latterly with the hydraulic questions of time of flow and the effects of various works in the connecting waters between Chicago and St. Louis.

Q. Are there any other cases with which you have been connected, in which these questions have been involved?

A. I was connected with the case at London, Ontario, involving the general hydraulic problems of back water and damage to millwright properties. I do not recall any other case that I have been connected with in which the sanitary element was important.

Q. Were there any in which water power or hydraulic questions have been involved?

A. Yes, I was engaged in a case here in New York between the City of New York, the New York Water Department and the New York Sugar Refining Company, the water stealing case which involved measurements of water by certain devices.

I was engaged in a case at Kalamazoo, between the City of Kalamazoo and the Standard Paper Company. I believe it was another water stealing case, which involved the measurement of water.

I was engaged in a case between the City of Flint and Mrs. Loranger involving the case of damage to water power by diversion of water.

I was engaged in a case in Illinois involving constructions in the Desplaines River, and their effect upon certain lands.

I was engaged in the case of United States *vs.* the Chandler-Dunbar Water Power Company and the Edison Sault Electric Company and others, to which I have already adverted, which was pretty nearly the essence of hydraulic engineering. And I was also engaged in the case of City of Ithaca *vs.* The Ithaca Water Works Company and others, for the condemnation of Water Works Property, which involved numerous hydraulic problems.

Q. What were the subjects involved in the case of United States *vs.* Chandler-Dunbar Water Power Company?

A. That was a case brought by the United States to acquire the property and lands of the Chandler-Dunbar Water Power Company and the rights of its lessee, the Edison Sault Company in the St. Mary's River, for the alleged purpose of utilizing the said property for the construction of locks in the improvement of navigation. The case involved the determination of the value of the property, and incidental thereto was of course the question of the amount of water power that could be developed there, the fall in the river, the natural and high and low flows and the benefits to navigation and various other collateral items.

Q. Those were the hydraulic questions involved that you just last mentioned?

A. Yes.

Q. Now your practice has taken you over a considerable scope of the country, hasn't it?

A. Yes.

Q. Will you state in a general way what States or cities your practice has involved?

A. I have practiced very largely in Michigan and New York; to a less extent in Illinois, Wisconsin, Minnesota, Massachusetts, both the provinces of Ontario and Quebec, Ohio, Colorado, Dakota, Missouri, and have had occasion to report upon and advise in the construction of works in Arizona, Washington, Pennsylvania. I think that is the list.

Q. Are you familiar with water purifications and the ordinary problems of sewerage, and if you are, state what investigations you have made, or what your practice has been in connection with those problems?

A. I have been for many years interested in the subject of water purification, my attention having first been called to it when I was serving as civil engineer to the Board of Water Commissioners of Detroit; and later I was associated with Mr. Allen Hazen, in the design and construction of a water purification plant for the City of Ithaca, New York, which was built under our supervision. And following that, I designed and constructed for Cornell University a plant for the purification of its water supply; and have been called upon to investigate and examine into various propositions or plans for water supply improvement. I was recently called upon by the Board of Water Commissioners of Detroit to make an examination of the conditions of the Detroit Water Supply, and submitted a report a few weeks ago, which has not yet been published, covering that subject. That involved an in-

vestigation of the lake water supplies in general, including those of Chicago, Milwaukee, Cleveland, Buffalo, Erie, and some of the others.

In the matter of sewage, I have done less. I have designed one or two small sewerage systems, in which case water disposal was used.

I have of course been familiar with the problem of the disposal of sewerage along the Great Lakes, from my acquaintance with it in my birthplace, the City of Saginaw, and later from my extended residence in Detroit, where I was brought into close contact with problems of that nature.

Q. In a general way, how are the waters of the Great Lakes used?

A. The waters of the Great Lakes afford the principal source of water supply for a very large portion of the population resident along their borders. All the large cities on the Great Lakes take their supplies from them or their connecting waters; and these supplies are used for domestic and manufacturing purposes, for the ordinary requirements of urban populations.

They are further used for the purposes of transportation or of navigation. And they are used, at places where circumstances permit, for the development of power; so that you might say that the water of the Great Lakes are used for practically all purposes for which water, natural waters are used.

Q. In your study of the Great Lakes system, and the water supply, have you considered whether there was any relation between the levels of the different lakes?

A. Yes, there is a very marked relation between them, which is influenced in two ways. Beginning with Lake Superior, it discharges through the St. Mary's River into Lake Huron, and any variation in the discharge of Lake Superior will be felt in the amount of water that is received by Lake Huron and Lake Michigan, which are practically one lake; so that a decrease in the flow of the St. Mary's River will have the effect of decreasing the quantity of water supplied to these lakes; and if other conditions remain the same, the lakes will be lower. An increase would raise them, other conditions being the same.

Any change in the levels of Lake Michigan and Lake Huron will be reflected in the discharge of the St. Clair River, which, emptying through Lake St. Clair into Lake Erie, will have the effect of raising or lowering the level of Lake Erie.

Similarly Lake Erie discharging through the Niagara River, if any change in its elevation occurs, it will change the quantity of water flowing through the Niagara, and this in turn will be reflected in the elevation of Lake Ontario, which finally supplies the water to the St. Lawrence River. So that we may say that a change in the amount of water reaching Lake Superior will be felt in the amount of water flowing in the St. Lawrence River.

Then there is, excluding Lake Ontario and Lake Superior, a reflex action. If a large quantity of water be supplied to Lake Erie, for instance, from its drainage area, that will have the effect of raising the lake and thereby decreasing the fall between Lake Erie and Lake Huron, reducing the flow into the St. Clair and Detroit Rivers, and raising the level of Lake St. Clair and likewise Huron and Michigan. So that we may say, so far as the three lakes are concerned, Erie, Huron and Michigan, that a change in one will be reflected in the other; and by reason of the fact that the different latitudes, or slightly different latitudes leads to the melting of the winters snows at slightly different times, and also on account of the storage possible in the lakes themselves, we find that the fluctuations of one lake follow the fluctuations of the other at quite regular intervals; the increase of level of one producing or tending to produce the high water in the one next lower down, at some later period.

Q. Are there any changes in the levels from day to day, month to month or year to year?

A. Very marked changes appear from day to day.

Q. Or from hour to hour, I may ask?

A. Yes, from hour to hour, under certain circumstances, quite extensive vibrations. Changes of one foot or two feet within an hour are not uncommon. And while the average changes from month to month are not so great as that ordinarily, the changes from year to year are considerable, covering a range of some two or three feet on Lakes Huron and Michigan; and I do not recall just the change of stage on Lake Erie at the present moment.

I wish to make a correction there: In speaking of daily changes or hourly changes, they are not changes of stage; they are changes of water at particular points. The monthly changes we call stages.

Q. Those last are sometimes designated oscillations?

A. Oscillations of the lake.

Q. What are the different causes as far as is known, which effect change of stage and oscillation of the lake?

A. The changes of stage are of course brought about by variations in the quantity of water which flows into the lake, and variations in the quantity which flows out. The oscillations are due to the effects of wind and the changes in barometric pressure; the barometric pressure at one end of the lake perhaps being greater than at the other, naturally depresses the surface of the water at that end and causes a rise at the other end. Or the same may occur across the lake. Those effects are, of course, of limited duration, but they cause decided changes of elevation at the extremeties of their effects. As for example on Lake Erie, it is not infrequent, or has not been in the past, that a variation of four feet might occur at one end of the lake; that is, it might be two feet below its natural position or two feet above, and in some cases higher fluctuations than those have been recorded. Those are usually due to the effects of wind sweeping lengthwise of the lake, possibly accompanied by barometric inequalities at the two ends.

I believe there is on record, in fact I know that there is a variation of six feet at the western end of Lake Erie; that is three feet below and three feet above the normal water plane; and that the fluctuations of Erie are sufficient at times to temporarily reverse the flow of the Detroit River so far as the same can be observed by ocular observation. Such occurrences are rare, but one of them has been within my individual observation.

Mr. Wilkerson: Are you able to fix the date of that?

A. It was somewhere between 1893 and 1897, while I was connected with the Detroit Water Works, between 1893 and 1898, I will say.

Mr. Adcock: What is the greatest range of the daily oscillations or changes in level at any particular point of Huron that you know about, Lakes Huron and Michigan being treated as the same lake?

A. I don't think that I can testify from personal observation to a daily change on Lakes Michigan and Huron.

Q. Have you any records or observations made of gauges which would show that?

A. Yes, I have, which would show some. That is, the records are based upon the records furnished from the office of the United States Lake Survey. I find I do not have them in the room; I can produce them later.

Q. Do you know the drainage areas of the different lakes?

A. I know them, yes, as I know other things which are matters of common knowledge.

Q. Do you know what the extent of the areas is?

A. Yes. The drainage area of Lake Ontario, exclusive of the lake itself is about—and that is exclusive of anything tributary to the lake above Niagara, above the head of the Niagara River—is about 25,737 square miles.

Q. What is the area of the lake itself? You might give that at the same time?

A. And the area of the surface of Lake Ontario is about 7,243 square miles. The drainage area of Lake Erie and St. Clair, exclusive of the lakes themselves and of anything above the head of the St. Clair River is about 30,296 square miles.

Q. And the lake area?

A. And the area of the lake surfaces is about 10,471 square miles of which about 500 square miles is in Lake St. Clair. The area of Lakes Michigan and Huron together, or rather, the drainage area of Lakes Michigan and Huron, exclusive of the drainage above Sault St. Marie is about 92,493 square miles, and the area of the lake surface is about 45,314 square miles.

The drainage area of Lake Superior exclusive of the lake surface is about 44,074 square miles and the area of the lake surface is about 32,060 square miles.

The land drainage area of Lake Michigan is about 43,463 square miles and the area of the water surface is about 22,336. The land drainage of Lake Huron is 49,710 and of the water surface 22,298.

Q. How is the water supplied to the Great Lakes?

A. The water supplied to the Great Lakes comes directly on to their drainage areas, and on to their surfaces as rainfall.

Q. Sometimes called precipitation?

A. Sometimes called the precipitation. And the source of this supply is probably to a very large extent the Atlantic Ocean and the Gulf of Mexico. In fact whatever is contributed to the ocean through the St. Lawrence River must be brought back in the form of rainfall and redeposited upon the drainage areas; otherwise the lakes would run dry and the ocean would fill up and drown out all the land.

Q. That would be true also of any water supplied to the Gulf of Mexico, wouldn't it?

A. Yes.

Q. Has there been any measurements of rainfall from time to time in the last period of years by any one?

A. The measurements of rainfall have been carried on at various places on the drainage areas of the Great Lakes for a great number of years. In the early days, these measurements were taken usually by individuals who were interested in the subject; and search of the old records will find in almost all our larger cities the history or record of some one who kept rainfall observations for a greater or less time. These observations were taken up by the United States Government along in the late sixties, I think, or indirectly the Smithsonian Institution apparently either collected the records from various sources or exercised some charge over their collection. Then there was for a time a so-called United States Weather Service which was later incorporated or transferred to the corps of engineers of the United States Army. I think not to the corps of engineers but the officers at United States army posts were expected to take and report rainfall observations.

Later, the present Weather Bureau was organized and since that time a systematic, a more systematic administration of rainfall and general meteoriological observations has been kept up. These observations, as we meet with them now, are comprised in perhaps three classes: First, and best, those taken by the regularly established weather bureau stations, which are located in most of the large cities and in some other strategic points, you might say, throughout the country.

The next in order is the record of various observers who have worked or are working under the authority of various states; there having been in several of the states a weather service at one time or another, and in some I believe it is still continued.

Then beyond that, and that upon which we are to a large extent dependent for the rainfall in the more remote regions, is the records prepared by you might say a vast army of volunteer observers. The United States Weather Bureau encourages any one who is interested in the observation of rainfall, temperature, evaporation or anything of that sort, by furnishing them now with a set of standard instruments for the observations which they are preparing to take, and asking that they make reports monthly to the Section Director of the Weather Bureau Service, in the particular state or region where they are located. In that way a large amount of information is gathered from localities which could not be reached or represented by the stations at which paid observers are

maintained. And still there is undoubtedly a large margin of error in this, as the observer will be found frequently to neglect to observe for a month or two here and there, or probably they oftentimes omit days of rainfall and so on, still taken as an average the country over it is probable that the relative values are reasonably correct. That is, we have no reason to suppose that observers in Minnesota would be any less lax or more lax than those in the State of New York; and that when we take the result of the observations of a large number of these observers and compare them with the results of a large number in some other locality, the relative indications we may assume to be quite reliable while the absolute indications, that is as to the actual amount, may be very largely in error.

The observations of the United States observers themselves, I think we are safe in saying, are quite accurate for the places where they are observed, but of course they do not cover the entire region by any means, and only represent accurately as to time a comparatively small area; though when considered as the mean of a year, the mean rainfall indicated for a year by these government observations, it is probably—I may say thoroughly representative of the mean rainfall for the region, unless you happen to meet with those conditions which change the character or the amount of precipitation, such as a mountain range or range of high land, or proximity to a large body of water.

For example, in the State of Michigan, the western side of the state receives appreciably more rain than the eastern side. That appears to be due to the fact that the rain mainly comes up through the Mississippi Valley from the Gulf of Mexico, and the western side of the state gets it first.

It is also noticeable, that where a mountain range intervenes between the source of the water in the atmosphere that the side away from the source will be dry and the side towards the source will receive much more rainfall. That is particularly noticeable in the western part of the United States, where the area between the coast range and the Pacific is supplied very bountifully with rainfall; after you pass the coast range, there is less, and by the time you get past the Sierras, you have practically a sterile—practically a desert, except at times of melting snow.

Q. What becomes of all this rain that falls upon the drainage area and the lake surfaces of the lakes?

A. The rain which falls upon the drainage area, upon the

land area, is disposed of usually, we say, in three ways: By evaporation, that is, the evaporation, by surface run-offs, and by percolation. A large part of it, in fact more than half, is re-evaporated either through the direct action of the rays of the sun upon the particles of water, as they lie upon the surface of the earth, or the branches and leaves of the trees and so on, or may be through the agency of the trees and vegetation itself, which takes up the moisture from the soil through its roots, passes it through its stem in the form of sap and exhales it from its leaves in the form of moisture.

The evaporation of different plants is markedly different; some apparently evaporating three or four times as much as others. The rain that falls upon the earth's surface in times of heavy downpours, or when the surface is frozen, or in the time of thawing of snows in the spring—or rather I should say that is on the surface under those conditions, a considerable portion flows off from the surface as visible run-off, as we see it in the ditches along the side of the road and in the small streams which you notice flowing through the fields, after heavy rains. It flows off into the rivers, creeks, and ultimately to the Great Lakes and to the ocean, speaking of the drainage of the Great Lakes.

Another portion, depending very largely upon the character of the soil, and to some extent on the character of the vegetation, finds its way into the soil and flows through it and furnishes the water supply which we ordinarily obtain from wells, either shallow or deep. This water, to a large extent, appears to return to the streams themselves and influences the discharge or the run-off as we call it, that is measured as surface run-off. Some of it of course reaches the Great Lakes through their sides and through the bottom, but——

Q. That is called subterranean passages, isn't it?

A. We hardly would call it subterranean passages, because there is really no passage in the sense of its being a channel or conduit, but it is simply the gradual percolation of the water through the sands and between the grains of the soil. And while it has never been possible to measure the amount of that flow into the Great Lakes, such information as is available on the subject, namely, as to the yield of wells which have been put down along the lake shore at various points where the supply comes from this current of water that is moving slowly through the earth, indicates that the amount of that run-off to the Great Lakes must be small.

Mr. Wilkerson: That is entirely in the realm of speculation, isn't it?

A. No, I don't think it is entirely. No, I think we have good reason to come to the conclusion that the amount reaching the Great Lakes through the underground surface is relatively a very small factor.

Mr. Adcock: Is there in your experience and from the records which you have examined, can you state whether there is any relation of evaporation to rainfall?

A. There is a relation, or there are certain relations. The law connecting rainfall and evaporation has not yet been worked out, and it is one of the most complicated problems that is to be encountered. Some of the conditions which must be included in the statement of any such law are quite well understood.

In the first place, as I have already said, rainfall falling upon the ground when it is frozen will run off very rapidly into the water courses, and a very large per cent. of it will appear as run-off. Rainfall falling on a sandy area which is not frozen will to a very large extent be absorbed by the earth; will pass through in the form of percolation to the streams which drain that area, and will ultimately reach the Great Lakes. The rainfall falling upon a cultivated area, at times when crops are growing, will to a very large extent be re-evaporated by the crops, and of course would appear in the atmosphere.

The evaporation is influenced by temperature, and by the wind, and by the amount of moisture in the air, so that we are pretty safe in saying that during a rain there is not much evaporation, so that it follows if you have, for instance, say three inches of rainfall in a month distributed in small showers, so that it covers a large number of hours, that is .02 of an inch at a time, perhaps the evaporation from water surfaces would be materially less, very much less under those conditions than it would be if it came in one or two large showers and evaporation was allowed to continue during the intervening periods, or would continue, as it must, without interference. That is one of the things that makes it extremely difficult to correlate the amount of rainfall with the amount of run-off or the amount of evaporation, because the same amount of rainfall delivered in one way may be productive of a very relatively large amount of run-off, whereas delivered in another way it nearly all goes off in evaporation and you have very little left in the run-off.

The comparisons of run-offs of various streams in Michigan which I have studied for a number of years show a quite wide variation in the amount of water—in the percentage of rainfall that appears as run-off; those streams coming from sandy areas giving relatively large run-offs; those streams coming from highly cultivated areas giving small run-offs.

The comparison of the streams in the west, that is, in the Central States with those further east, say in Central New York, where the country is much more precipitous indicates that the percentage of run-off in the New York streams is considerably greater than that in the Michigan and Wisconsin and Illinois streams, by reason of the fact that the rain that falls flows quickly into the streams and is carried off quickly before it has time to evaporate. There are all those conditions that have to be taken into account. For example, the run-off from the State of Ohio is noticeable for its smallness relatively to the others. The high cultivation apparently, combined with the character of the soil, which is a loam, and with the character of the surface, which is moderately rolling, seems to conduce to a very high evaporation or a very large absorption by plant roots, and subsequent evaporation so that the run-off from the Ohio streams, both those which flow into Lake Erie and those which flow into the Ohio River, is considerably less than is run-off of those streams that flow into Lakes Michigan and Huron, or into Lake Ontario.

Q. Is there any difference in evaporation of different drainage basins of the Great Lakes, drainage areas of the Great Lakes?

A. Yes, there undoubtedly is. Such observations as have been made indicate such to be the fact. And there appears to be a larger evaporation from the basin of Lake Erie than from either that of Ontario or of Michigan and Huron; and the evaporation from Lake Superior, though the observations are less complete than elsewhere, appears to be materially less than that from the lakes lower down, which is of course to be expected on account of the general lower temperature, both of the air and of the water.

Q. As a result of the evaporation taking place more rapidly in the summer time, when is the lowest stages of the lakes usually, during the year?

A. They are usually in the fall or winter, if I remember rightly; rather in the winter, for the lake stages during the navigation season are in general higher than they are during

the average of the whole year. In general the low period is in February and March; that is the late winter.

Q. You are referring now to what?

A. Complainant's Exhibit 5.

Q. Has the run-off of the various rivers supplying the lakes been measured in any way?

A. Run-off observations have been taken covering periods of years on a large number of rivers flowing into the Great Lakes. These observations are largely compiled by the United States Geological Survey, although the observations covering the New York streams—a very considerable amount of information covering those streams is to be found in the reports of the State Engineer of New York, and some other sources; the report of the Board of Engineers on Deep Waterways contains a discussion of them.

From an examination of that information and other information, with which I was personally familiar, I find that run-off observations have been taken covering about 37 per cent. of the drainage area of Lake Ontario; about 33 per cent. of the drainage areas of Lakes Erie and St. Clair, and about 32 per cent. of the drainage areas of Lakes Huron and Michigan, all being exclusive of the drainage areas of the lakes next above. The run-off observations of streams supplying Lake Superior are limited to one or two streams, and are too limited to give any very definite information.

Q. We have heard a good deal about the terms "increment," Mr. Williams. I would like to ask you to define that word if you can?

A. The term increment as used in this case has a peculiar significance. As used in general, it means any change or increase of a changing quantity. In this case it means a specific change or the amount of change in the discharge of one of the rivers—of any of the rivers that is due to an increase of elevation of one foot in the controlling lake. So that when we use the term increment here, we mean the amount of water by which the flow of the river in question would be increased by the rise of one foot in the lake which is supplying the water or which is controlling or assumed to control the discharge.

Q. Is it applied in the same way to the lowering of one foot?

A. Yes. It is the amount of water by which the discharge would be changed by a rise of a foot or the fall of a foot, and for the purposes of this case within the range it has been used, it has been assumed that the increment due to a rise of

a foot is the same as the increment due to the fall of a foot; and the observations show that to be substantially correct, while absolutely or theoretically it is not.

Q. For all practical purposes it is the same?

A. For all practical purposes, within the ranges that are dealt with in this case, it is the same; or within the ranges that have been dealt with thus far in this case.

Q. So that you, in using the term increment, you refer to the increment say of the St. Clair River, Detroit River or Niagara or St. Lawrence Rivers?

A. Yes.

Q. Why is it necessary, in connection with the investigations that have been made to determine the effect of a diversion of water, say at Chicago, why is it necessary to obtain an increment of, say the St. Clair River?

A. Because that is the only way in which the effect of a diversion of the magnitudes considered could be determined. The magnitude of the diversion is so small as to be insusceptible of any direct observation or measurement; and the only way in which a measure of its effect can be obtained is by ascertaining how much the flow would be increased or decreased by the change of a foot. Then conversely the change of so much flow would change the level a foot, and of less than so much would change it a proportional part of a foot.

Q. Do the fluctuations of, say, the controlling lake have any relation to the increment of the outlet of that lake?

A. Yes, they are very intimately related considering or dealing with the changes of stage over a considerable period of time as a year, for instance. The greater the change of stage in annual fluctuation, or in fluctuation from year to year, the less must be the increment, and vice versa, a lake which changes but slightly in its surface elevation gives indication of a large increment and one which changes greatly gives indication of a small increment of the quantities of water flowing into the two lakes, is reasonably near the same amount. If, for instance, a lake having a smaller quantity of water shows a higher fluctuation than a lake having a larger quantity of water flowing into it, the indication is conclusive that the increment of the lake which shows the higher fluctuation is less than the increment of the lake having the lower fluctuation.

This can perhaps be illustrated by taking a trough and putting two partitions in it, and allow water to flow down it. If you have an opening in one partition that is, say, four inches square, and an opening in the other partition of the same size,

if you raise the water in the upper section of the trough, in a reasonable time it will rise correspondingly in the lower section. But if in the lower section there is an opening which, let us say, is four inches deep and eight inches wide, the water in the lower section will not rise as high, in fact actually something less than half as much as it is raised in the upper section.

In other words, the increment of the discharge through the lower partition is more than twice as great, for these exact figures, than the increment of discharge of the upper section. So that it follows that the relation of the increment is inversely as the relation of the fluctuations.

In other words, you can say if the fluctuation of one lake is twice as great as the fluctuation of the other, then the increment of the first lake must be about half as great as the increment of the other.

Mr. Wilkerson: You are speaking now with reference to continuous flow?

A. I am speaking now with reference to continuous flow.

Mr. Adcock: So that if you found in one period of a number of years the fluctuations of a particular lake, like Lake Huron, for instance, were greater than another period of years, it would be assumed that the increment had changed?

A. I think that would be conclusive evidence, if both covered reasonably long periods. I would not say that a comparison of fluctuations for one or two years would be sufficient, but if you had 15 or 20 years in a period, I think you would be quite safe in drawing that conclusion.

Q. When you refer to fluctuations of the lake in connection——

A. I mean real change of stage for considerable periods of time.

Q. Real change of stage, and yearly fluctuations?

A. Yes, from year to year.

Q. Not of monthly?

A. Not the monthly.

Q. Why do you eliminate the monthly fluctuations in connection with determining the relation of the increment?

A. Because in the monthly fluctuations there is not time for the effect of the storage in the lakes to work out. It takes time for the lake to rise, and if you deal with monthly fluctuations, one lake would not have yet followed the other closely enough to warrant a judgment. That is, your second lake

would be lagging too far behind the first one, so that you might be misled in your conclusions.

Q. Is there any relation between the increase of the increment and the discharge of the river?

A. Yes, that depends upon the form of the channel to some extent, but it may be demonstrated by the ordinary laws of hydraulics and physics that the change of increment cannot be greater than the change of discharge. That is, that if you have a certain channel which has a certain increment, and by changes in that channel made below the surface of the water you increase the increment, you must have increased the discharge in at least as great a proportion.

Q. Why do you say in at least as great a proportion?

A. Because that is the limit. They could only be equal in the case of an extremely large channel, with an extremely small change, but in any change that becomes appreciable the magnitude of discharge will be changed to a greater extent than the increment is changed.

Recess to 2 p. m.

After recess—2 p. m.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Mr. Adcock: From your study and experience have you become and are you now familiar with navigation upon the Great Lakes?

A. Yes, I have been familiar with the conditions of navigation and with navigation for the greater part of my life.

Q. What is the general course of travel, of boats carrying freight upon the lakes, the Great Lakes?

A. The largest part of the traffic of the Great Lakes above Ontario is composed in tonnage, the largest part in tonnage is composed of ore.

Q. That is iron ore?

A. Iron ore. This traffic originates mainly at Lake Superior ports; Superior, Duluth, Ashland, Marquette.

Q. You are referring now to Complainant's Exhibit 6?

A. Complainant's Exhibit 6.

Q. Entitled "General Chart of the Great Lakes?"

A. General Chart of the Great Lakes. It passes through Lake Superior, the St. Mary's River, and divides, a small

portion of it going to the Straits of Mackinaw to South Chicago; and by far the largest portion going through Lake Huron and St. Clair River, Lake St. Clair and the Detroit River to Lake Erie ports, Cleveland and Ashtabula particularly.

There is also a considerable amount of ore from Escanaba, which is at the northern end of Green Bay. This passes out into Lake Michigan and divides, a portion of it going to South Chicago down to Lake Michigan, and the other portion passing eastward through the Straits of Mackinaw, and joining the traffic from Lake Superior on its way to the Lake Erie ports.

Q. What is the traffic below Lake Erie, or from Lake Erie to other points?

A. Going down from Lake Erie, the depth of navigation is controlled by the depths of the Welland Canal, first which connects Lake Erie and Ontario; and then by the depth of the Canadian canals along the River St. Lawrence, so that it follows that deep draft boats are not in use on Lake Ontario; and in 1911 there was no boat on Lake Ontario drawing more than 14 feet.

Of course in addition to this ore traffic, there is a large passenger traffic, and a considerable traffic, in package freight, which moves in both directions, up and down through the lakes. And a traffic in coal northward at certain seasons of the year which moves from the Lake Erie ports to ports along Lake Superior and Lake Michigan. This coal traffic is largely carried by the ore boats on their return trips; and there are comparatively few boats used in it alone and the draft of their boats is very much shallower than that of the ore carrying boats. I have a memorandum of that, I think, which I took the other day. A few days ago I examined the boats of the Detroit & Cleveland Navigation Company that were tied up at Detroit. These embraced the two largest boats of the fleet, the City of Cleveland Third, and the City of Detroit Third, upon which the highest marks were for 15 and 16 feet. Those were at the stern. The bow marks were 14, in the case of the City of Cleveland. I was in error in stating that 16 was the highest on the Detroit. The stern mark on the Detroit was 17. The City of Mackinac and City of Alpena, both being "Second" so-called, which ply from Detroit to Mackinac, at their sterns were marked 11 and 12 respectively.

Q. That is feet?

A. That is feet. And it is not customary for those boats to load beyond their marks, as I have seen them many times

and I have never seen them when the marks were obscured. In fact they could not load lower than that, without interfering with their paddle boxes.

Q. Now you have described in a general way the course of travel of the boats, of the freight carrying boats. I have here a chart marked "Lake Superior," issued by the United States Lake Survey. I ask that it be marked Defendant's Exhibit 1 of this date.

(Whereupon chart referred to was marked Williams Exhibit 1, March 18, 1913.)

Q. What does that chart show?

A. That chart shows the geography and hydrography of Lake Superior, the outline of the lake and the immediate shore topography is shown and also the depth of water at various places throughout the lake, where soundings are indicated by figures, and also the courses of navigation, which are indicated in general by dotted lines from point to point along the lake.

Mr. Wilkerson: These small figures are depths?

A. They are depths in fathoms.

Mr. Adcock: How much is a fathom?

A. Outside of the blue, the depths are in fathoms of six feet. Inside the blue the depths are in feet.

Q. Now a boat, an ore boat, for instance, passing from Marquette out of Lake Superior, at what point does such a boat leave Lake Superior?

A. At the head of the St. Mary's River; that is it enters St. Mary's River.

Q. Is there a bay called Whitefish Bay?

A. Whitefish Bay.

Q. Now, I show you another chart issued by the United States Lake Survey, which I ask be marked Williams Exhibit 2 of this date, entitled "Chart 3. St. Mary's River." From that chart, Mr. Williams, can you indicate or state what course a boat will follow going down through the St. Mary's River and the lakes?

A. It will come into the head of St. Mary's River from Whitefish Bay and follow down through the deep water in the river, angling to the left above Round Island, and following the river down to a point about two miles about the locks, where it may choose between taking the Canadian Channel to the northward, or coming through the American locks, which are on the south side of the river at the Falls.

Q. When you say Canadian Channel, you mean also Canadian locks, don't you?

A. I mean also the Canadian locks; passing through the canal either on the Canadian side or the American side. It then passes into the lower river and proceeding down below the City of Sault Ste. Marie it has a choice of taking the Canadian Channel or the American channel. The practice at present is for the loaded boats to take the American channel I believe. The Canadian channel, the Lake George Channel communicates with the Georgian Bay, and is used mainly by boats plying in that direction?

Q. Is the depth of the water indicated on this chart by the figures?

A. It is indicated on this chart in feet.

Q. All the way in feet?

A. Yes, sir, apparently all the indications are in feet.

Q. In the blue as well as the white?

A. Both in the blue and the white.

Q. I show you another chart issued by the United States Lake Survey entitled "St. Mary's River. Chart 2," which I ask be marked Williams Exhibit 3 of this date. In a general way what did that chart show with reference to the St. Mary's River and the channel there?

(Chart shown to witness and marked Williams Exhibit 3, March 18, 1913.)

A. That chart shows the river below Sault Ste. Marie, or practically from the lower end of Sault Ste. Marie to Mud Lake.

The Lake George Channel is seen in the northern end of the chart, going into Lake George and thence out to St. Joseph Channel into Georgian Bay. The main improved channel from Sault Ste. Marie to Hay Lake is close to the American shore, and below Hay Lake the channel divides, one passing down through the West Neebish, and the other to Mud Lake, or through Little Mud Lake, and the two uniting in Mud Lake Proper.

Q. What does the blue on that map indicate?

A. The blue indicates shoal water, and the white indicates water deeper than 21 feet.

Q. Now take the course of the boat from where you left off on the other chart.

Mr. Wilkerson: Is that same thing true of the preceding charts?

A. That is true of all of them until you get to Ontario.

Mr. Adcock: Will you state what course the boat would follow in its downward course?

A. The loaded boat would pass down into Hay Lake through the main improved channel on the American side and then take the right-hand or western channel through the West Neebish; the eastern channel through by way of Sailors' Encampment, Little Mud Lake being reserved for up-bound boats. From Mud Lake the channel passes or the course passes through the lake southeasterly to the next chart.

Q. Which is Chart 1, which I have in my hand, which may be marked Williams Exhibit 4 of this date, entitled, "Chart No. 1, St. Mary's River." Now will you state in a general way what that chart shows?

(Chart shown to witness was marked Williams' Exhibit 4, March 18, 1913.)

A. That chart shows the lower end of the St. Mary's River with the outlet into Lake Huron. The course from Mud Lake is bearing southeastward and then turns almost due south and then to the eastward again; finally south through the Detour Passage.

Q. Is the depth of water indicated on that chart in the same manner that it is on the other charts that you have mentioned?

A. Yes, the indication here is in feet, both in the blue and in the white, and the blue represents water less than—the white represents water 21 feet in depth.

Mr. Wilkerson: How far is it from the falls down to Lake Huron?

A. I don't remember, but about 40 miles.

Q. About 45 miles?

A. I may add that the St. Mary's River enters Lake Huron a comparatively short distance east of the Straits of Mackinaw.

Mr. Adcock: I show you another chart here entitled, "Lake Michigan," issued by the United States Lake Survey, and ask that it be marked Williams' Exhibit 5 of this date. What does that chart show?

(Chart shown to witness was marked Williams' Exhibit 5 March 18, 1913.)

A. That chart shows Lake Michigan, including Green Bay and the Straits of Mackinaw. It does not extend quite over to the mouth of the St. Mary's River.

Q. Boats bound for Chicago and points at the lower end of Lake Michigan, what course would they take?

A. They would pass westward through the Straits of Mackinaw and may then pass west to the westward of Beaver

Island, or the Beaver Island group, in which case they will have a good depth of water; or they may take the passage to the east of the Beaver Island group, which is somewhat narrower, but involves a shorter distance. This permits them to pass either east or west of the Manitous, and down Lake Michigan.

Q. Is the depth of water indicated there upon the map in fathoms or in feet, by the figures?

A. That is indicated in fathoms in the white and in feet in the blue.

Q. Take the boats going from Escanaba to South Chicago, will you describe their course?

A. Escanaba is on the northern arm of Green Bay. A boat would pass south in Bayde Noch and then southeasterly through some one of the passages between the islands which divide Green Bay from the main lake, and then southward the length of Lake Michigan.

Q. Will you describe the course of those boats which are going from Escanaba to Cleveland, say?

A. They would pass eastward, as soon as they pass out of Green Bay, and pass through the Straits of Mackinaw, either by going north of the Beaver Island group or south of it.

Q. Here is a similar chart entitled "Lake Huron," which I ask to be marked Williams' Exhibit 6 of this date. State in a general way what is shown on that chart.

(Chart shown to witness was marked Williams' Exhibit 6, March 18, 1913.)

A. That chart shows the outlet of the St. Mary's River, or the mouth of the river, Georgian Bay, or the north channel, more properly called, and Georgian Bay lying to the eastward, and Lake Huron; also the Straits of Mackinaw in the northwestern corner of the chart.

Q. Is the depth of water indicated there in fathoms or in feet?

A. The depth of water is indicated in fathoms in the white and in feet in the blue.

Q. Now will you describe the course of a boat going from the St. Mary's River to the St. Clair River?

A. Coming out of the St. Mary's River it bears somewhat easterly of south, perhaps south southeast, and the line is very nearly straight, having a slight curvature to the eastward.

Q. At what point?

A. I mean it is very nearly straight from here to the mouth of the St. Clair River, having a slight curvature to the east to

avoid the region in the vicinity of Alpena and again at Sand Beach.

Q. I have here a similar chart entitled "St. Clair River," which may be marked Williams' Exhibit 7. Will you indicate what is shown on that chart in a general way?

(Chart shown to witness was marked Williams' Exhibit 7, March 18, 1913.)

A. That chart shows the St. Clair River from Lake Huron to Lake St. Clair. It is made up in two principal sections, one reaching from Lake Huron to the town of St. Clair and the other reaching from Stag Island, or from the foot of Stag Island, which is above St. Clair, through the delta into Lake St. Clair.

Q. How is the depth indicated on that map?

A. The depth is indicated in feet both in the white and in the blue.

Q. And the course of a boat going to Cleveland would be what, through the St. Clair to Lake Huron?

A. It would enter the St. Clair River at Fort Gratiot, and pass down the river following the main channel to a point opposite Algonac, when it takes the so-called "South Channel," or what is now known as the main channel through the St. Clair Flats Canal and out into Lake St. Clair following the dredged cut across Lake St. Clair.

Q. How many channels are there there which boats may take?

A. Through the Flats, or through the canal proper there are two channels, one used for down-bound and the other for up-bound traffic.

Q. How wide are these channels, do you know?

A. One of them is 290 feet and the other is 300 feet wide.

Q. Do you know the width of the St. Clair River from Huron down to the St. Clair Flats?

A. It is something less than 2,000 feet in the narrow portion, but generally between 2,500 and 3,000 feet. There are places where it is somewhat wider.

Q. Then from the St. Clair River, or St. Clair Flats, boats pass through—

A. Lake St. Clair.

Q. Lake St. Clair, which is shown on the chart entitled, "Lake St. Clair," similar to the ones which have been introduced in evidence, which I ask to be marked Williams' Exhibit 8. Now, Mr. Williams, what in a general way does that chart show, the one to which I have just referred?

(Chart shown witness marked Williams' Exhibit 8, March 18, 1913.)

A. That shows the outlet of the St. Clair River, or the lower end of the St. Clair River, beginning at a point about six or seven miles above Algonac and extending through Lake St. Clair to the head of the Detroit River.

Q. How is the depth of water indicated there?

A. The depth of water is indicated here in fathoms in the white and in feet in the blue.

Q. What would be the course of a boat going down on its way to Cleveland, say?

A. (No answer.)

Mr. Wilkerson: When you speak of the course of a boat, you mean the straight cut, so to speak, in fair weather, and not the course it might be obliged to take in the time of storms or when meeting with an accident that obliged it to lay up some place for repairs; you mean the straight cut?

Mr. Adcock: The ordinary course.

Mr. Wilkerson: In fair weather.

Mr. Adcock: Simply in a general way, the ordinary course so that it can be followed through.

A. The boat passes out of the St. Clair Flats Canal and through the dredged cut, which is something less than two miles in length into the deep water in the middle portion of Lake St. Clair. Then it passes in an almost straight line—

Q. In a general way, how deep is that water in the middle?

A. The water runs about 3½ fathoms, it is about 21 feet below the reference plane of this chart.

Q. The reference plane is what?

A. The reference plane of this chart is elevation 575.16 above sea level, which is about a foot and a half above the lowest monthly mean water as indicated on this chart.

The boat then passes into what is known as the Grosse Point Channel, which is six miles or five miles in length, perhaps, which is dredged through the shoal at the lower end of Lake St. Clair.

Q. Is the Grosse Point Channel indicated by any terms on that map?

A. The Grosse Point Channel is indicated by the white channel through the blue at the lower end of Lake St. Clair. It lies just north of a deep blue patch indicated as Grosse Point dumping ground, which is where material from the channel was wasted at the time the channel was built or constructed. And that takes them into the head of the Detroit River,

in the vicinity of Windmill Point and Isle Lopesch, which has been translated in the vernacular into Peach Island.

Q. At that point you enter the Detroit River?

A. The Detroit River.

Q. Which is shown on a similar chart entitled "Detroit River," Williams' Exhibit 9. That shows the Detroit River, does it, Mr. Williams?

(Chart shown witness marked Williams' Exhibit 9, March 18, 1913.)

A. That shows the Detroit River.

Q. From the head of St. Clair?

A. From the foot of Lake St. Clair at Windmill Point down past Belle Isle, City of Detroit, turning to the southward, passing by numerous channels, past Fighting Island and Grosse Isle to the region known as the Lime Kilns or Ballard's Reef, which constitutes the line of demarcation between Lake Erie and the river.

Q. How is the depth of the water indicated there?

A. The depth of the water is indicated on this chart in feet, in all cases.

Q. Both in the blue and the white?

A. Both in the blue and the white; the white indicating depth above 18 feet below the reference plane. The reference plan of this chart is 573.11, which is about 2½ feet above the lower recorded monthly mean as indicated on the chart.

Q. What do the new charts refer to?

A. In the right-hand portion of this chart is shown the Lower Detroit River to a larger scale, but this is more clearly shown on another chart.

Q. Entitled "The Lower Detroit River"?

A. Yes, entitled "The Lower Detroit River."

Q. What is the width of the Detroit River above Fighting Island?

A. Well, it is from 2,200 to 3,000 feet at most places.

Q. What is the width of the channel at Belle Isle, to the right of Belle Isle?

A. Opposite Belle Isle is a little over 2,000 feet wide on the Canadian side. It is considerably wider on the American side, but the channel is not so deep, and it is not used for navigation except by boats having local freight to take on or deliver at the docks along the front of Detroit, above the foot of Belle Isle; and by some passenger boats.

Q. So that the course of the boat would be on the Canadian side of Belle Isle?

A. Yes, passes to the south of Belle Isle.

Q. Then it would follow the channel down from Belle Isle to Fighting Island?

A. Follows the channel from Belle Isle to Fighting Island, passes to the westward of Fighting Island, to the eastward of Grosse Isle; then down through the Lime Kilns, or now through the Livingstone Channel into Lake Erie at Bar Point.

Q. I show you a chart here entitled "Lower Detroit River," which I ask to be marked Williams' Exhibit 10. I will ask you to state what that chart shows?

(Chart shown witness marked Williams' Exhibit 10, March 18, 1913.)

A. That chart shows that portion of the Detroit River lying to the eastward of Grosse Isle, from a point about a mile and a half above the head of the Livingstone Channel to Lake Erie. It is designated "Lower Detroit River," showing Livingstone Channel.

Q. From Stony Island down, what course would the boats follow generally, the ordinary course?

A. Down-bound boats at the present time are supposed to use the Livingstone Channel, which goes almost directly south from a point a short distance above Stony Island, while the up-bound boats take what is known as the Amherstburg Channel, or was formerly called the Lime Kiln Channel, which is to the right of Bois Blanc Island.

Q. Where is Ballard's Reef shown, if at all, on that map, that chart?

A. Ballard's Reef is shown at the top of this map. It is marked "Ballard's Reef" in the line of the main channel.

Q. And where is what is called the Lime Kiln Crossing?

A. The Lime Kiln Crossing is pretty nearly opposite Stony Island, a little bit to the south. It does not seem to be marked.

Q. Well, what points does it cover, can you indicate on the map?

A. The Lime Kiln is represented almost as being in the range of river that is covered by the coffer dam of the Livingstone Channel, which is indicated here parallel to the side of the main channel.

Q. Do you know how the elevation of Lake Erie compares with the elevation at the Lime Kiln Channel, what relation they have?

A. Well, ordinarily the elevation of Lake Erie is slightly lower than that at the Lime Kiln. I think there is about a fall of possibly, ordinarily, something around five inches.

Q. Is there a gage at Amherstburg, has it been maintained for some years?

A. There is a gage maintained at Amherstburg, and at times a gage has been read known as the Lime Kiln gage, which is opposite about the middle of the Lime Kiln or the lower end of it; also there have been numerous other gages at different times located along the river here; one at Mamajuda Light, which is at the upper end of this particular chart, which has been observed at times.

Q. Do you know the widths of the Lime Kiln channel as it exists today, at the present time?

A. The Lime Kiln Channel at the present time is 600 feet wide in its narrowest portions.

Q. That is the channel that the down-bound boats take?

A. No, that is the up-bound at present. It is the old channel.

Q. And the Livingstone Channel, what is the width of that?

A. The Livingstone Channel is 300 feet wide in its narrowest section, which is through that part of the rock that was excavated in the wet. Through the rock which was excavated within the dry, within the coffer dam, it is 450 feet wide, and down in the soft material it is widened to—I think gradually widens to about 1,200 feet.

Q. Will you indicate on the map where it was excavated in the soft and in the wet, and where the coffer dam is?

A. The coffer dam extends from a point practically opposite the upper end of Stony Island south for a distance—south, or down the river, for a distance of about 6,000 feet. Then comes the rock section which extends from this point—

Q. That was excavated in the wet?

A. That in the coffer dam was excavated in the dry. The lines of the coffer dam are shown here extending from Stony Island down to the—

Q. To a point indicated by—

A. Indicated by Light No. 6, Lights Nos. 5 and 6, which are on the west and east sides of the Livingstone Channel respectively, at the foot of the coffer dam.

Q. Then how far does that portion of the channel extend, which was excavated in the wet that you mentioned?

A. In the rock?

Q. In the rock.

A. That extends from the foot of the coffer dam to a point practically opposite Bar Point, and has a length of about 3½ miles. We then come to the portion which was excavated in earth, which extends for another four miles about, or 3½, into the lake.

Q. Before the Livingstone Channel was constructed, was

that portion of it that is now Livingstone Channel earth or water except where it was excavated?

A. It was water, but in many places quite shallow. At some points the water was not over four feet deep, at ordinary stages through the section where the channel now has been excavated.

Q. I show you a similar chart here which is entitled "Lake Erie," and ask that it be marked Williams' Exhibit 11 of this date. In a general way what does that chart show?

(Chart shown witness marked Williams' Exhibit 11, March 18, 1913.)

A. That chart while showing primarily Lake Erie also shows the foot of Lake Huron, the St. Clair River, Lake St. Clair and the Detroit River, to a rather small scale, but indicating their relative positions with reference to Lake Erie.

Q. How is the depth indicated on that?

A. The depth is indicated upon this chart in fathoms in the white and in feet in the blue.

Q. Now, will you indicate the ordinary course of boats going to Cleveland from the Detroit River, after they pass through the Detroit River?

A. Coming out of the Detroit River the boat bears a little south of east and passes through the passage between Pelee Island and Point Pelee and then bears directly into Cleveland Harbor.

Q. Is the Welland Canal indicated on that map?

A. Yes, the Welland Canal. This map also shows the Niagara River and the upper end of Lake Ontario. It shows the Welland Canal starting at Port Coburn on Lake Erie, and extending through to Port Dalhousie on Lake Ontario. It is located to the westward of the Niagara River.

Q. Do you know in a general way the freight that is carried to and from Buffalo or other harbors about Lake Erie?

A. I don't know the exact magnitude of freight that is carried to Buffalo. It is made up now largely of package freight and some grain. But the transportation of grain on the Great Lakes has been decreasing of late years, so that it is of less importance than it was some years ago.

Q. I show you a chart entitled "Buffalo Harbor," similar to the charts that have been introduced, and ask that it be marked Williams' Exhibit 12. What is indicated on that chart?

(Chart shown witness marked Williams' Exhibit 12, March 18, 1913.)

A. This chart shows the lower end of Lake Erie and the

Niagara River as far down as Niagara Falls. It also shows the start of the Erie Canal, bearing eastward from the river at Tonawanda.

Q. How is the depth indicted there?

A. The depth in this case is indicated in feet, both in the white and in the blue.

Q. What traffic is there on the Niagara River?

A. It is very insignificant, mainly passenger traffic except that which passes into the Erie Canal which really is not in the river.

Q. Do you know the depth of the Erie Canal?

A. The Erie Canal is being developed for barges 12 feet in depth.

Q. And the Welland Canal you stated to be what?

A. About 14.

Mr. Wilkerson: What do they call that canal? They are reconstructing it, aren't they?

A. New York State Barge Canal.

Mr. Adcock: I show you a chart here entitled "Niagara River," which has been marked Williams' Exhibit 13 of this date, and ask you to state what that shows.

(Chart shown witness marked Williams' Exhibit 13, March 18, 1913.)

A. That shows the Niagara River from the pool above the falls to Lake Ontario, and a small portion of Lake Ontario at the outlet of the river. The depths are marked in feet, both the white and the blue.

Q. I show you a similar chart entitled "Lake Ontario," which I ask to be marked Williams' Exhibit 14, and ask you to state in a general way what it shows.

(Chart shown witness marked Williams' Exhibit 14, March 18, 1913.)

A. This map shows Lake Ontario with the lower end of Niagara River and the upper end of the St. Lawrence River. The depths on this chart are in fathoms in the white, in feet in the blue.

Q. Are there any canals shown on that chart?

A. It also shows the Welland Canal, or a portion of it, that is all. It does not reach down far eough to catch the St. Lawrence Canal.

Q. Do you know what the character of freight is that is carried on that lake?

A. Mainly package freight.

Q. And from points—

A. From port to port.

Q. From port to port on the lake?

A. On the lake.

Q. I show you a chart here entitled "Chart No. 6, St. Lawrence River"; I ask that it be marked Williams' Exhibit 15. Will you indicate what that chart shows in a general way?

(Chart shown witness marked Williams' Exhibit 15, March 18, 1913.)

A. That chart shows the upper end of the St. Lawrence River, or what might almost be called the lower end of Lake Ontario, although it is really a part of the river. It represents a portion of the famous Thousand Islands. The soundings on this chart are in feet, both in the white and the the blue.

Q. As they are indicated by figures?

A. As indicated by figures. This does not reach yet to the head of the canal system.

Q. I show you another chart here which is entitled "Chart 5, St. Lawrence River," to be marked Williams' Exhibit 16. What does that chart show in a general way, Mr. Williams?

(Chart shown witness marked Williams' Exhibit 16, March 18, 1913.)

A. This chart shows a section of the St. Lawrence River from a point above Alexandria Bay down to Chippewa Point. This is still in the navigable portion of the river.

Q. At all points?

A. At all points.

The depths are given in feet both in the white and in the blue.

Q. I show you another chart here entitled "Chart 4 St. Lawrence River," which I ask to be marked Williams' Exhibit 17. What does this chart show?

(Chart shown witness marked Williams' Exhibit 17, March 18, 1913.)

A. This shows a portion of the St. Lawrence extending from Chippewa Point to about four miles below Brockville. The depths are indicated in feet both in the white and in the blue.

Q. I show you another chart here which is entitled "Chart 3, St. Lawrence River," to be marked Williams' Exhibit 18. State in a general way what this chart shows.

(Chart shown witness marked Williams' Exhibit 18, March 18, 1913.)

A. This chart shows a portion of the St. Lawrence River from a point about eight miles above Ogdensburg to a point about a mile below the Galop Island. We now come to that portion of the St. Lawrence River which is only half navigable. That is, boats may travel it in one direction but not in the

other. And we then get into the artificial channels along the Canadian side of the river which permits the return of boats which have passed down through the main stream.

Q. What channel is that, it is called the Northern Channel, is it?

A. The name is not on it here. It is the north channel, but that is not the canal. There are no locks there.

Q. How far is Ogdensburg from Lake Ontario, the foot of Lake Ontario in a general way?

A. About 67 miles.

Q. Is there any gaging section on the St. Lawrence River at or near Ogdensburg?

A. About 15 miles below at point Three Points which is not shown on this chart, there is a gaging section.

Q. Can you indicate about where that is?

A. Well, it will be on the next chart.

Q. Is there any gaging point—is there an Oswego gage?

A. Oswego gage is out in Lake Ontario, but the gage at Ogdensburg was used as the reference gage in the gaging of the St. Lawrence River.

Q. I show you chart marked "Chart 2, St. Lawrence River," which may be marked Williams' Exhibit 19 of this date. Will you describe that in a general way?

(Chart shown witness marked Williams' Exhibit 19, March 18, 1913.)

A. This shows the St. Lawrence River from the head of the Galop Canal down to Weaver's Point.

Q. Was there a gage section on the St. Lawrence River? Can you indicate where that was on this map?

A. That was in the vicinity of point Three Points, which is about a mile and a half below the Village of Iroquois on the Canadian side. That is one of them.

Q. I show you another chart here entitled "Chart 1, St. Lawrence River," which may be marked Williams' Exhibit 20 of this date. Will you describe that in a general way?

(Chart shown witness marked Williams' Exhibit 20, March 18, 1913.)

A. This shows the St. Lawrence River from Weaver's Point to St. Regis Island, and includes the Farron Point Canal, the Cornwall Canal, and gets us to the upper end of Lake St. Francis.

Q. Have the channels of the St. Mary's River, and the St. Clair and Detroit Rivers, been improved at any time by the United States Government?

A. Yes. These improvements have extended over a period

beginning back in the fifties, to date, and work is going on now, or was until the winter interfered with it.

Q. What was the original depth of the water in the St. Clair and Detroit Rivers before the improvements were commenced?

A. The original depths of the St. Clair and Detroit Rivers at the controlling points was about eight feet on St. Clair Flats; that is the foot of the St. Clair River, and about the same at the Lime Kiln Crossing or Ballard's Reef in the Detroit River. I mean by "controlling points" the points which regulated the depths or draft of boats that could pass up or down the river, passing through the system. That was the shallowest place in the river; those are the controlling points.

Q. In other words the shallowest place in the St. Clair River was at the St. Clair Flats, at the head of Lake St. Clair?

A. Lake St. Clair.

Q. At that time?

A. Yes.

Q. Then the controlling point or the shallowest place in the Detroit River, was at the Lime Kiln Crossing and Ballard's Reef?

A. Yes, in the region through the Lime Kiln.

Q. When was the first improvement made at those points if you remember?

A. The St. Clair Flats Canal was constructed about the time of the Civil War, or before; completed in 1858, giving a depth of 12 feet. Then between 1857 and 1871 it was deepened to 13 feet, and following that improvements were made both at the St. Clair Flats and the Lime Kiln, deepening the water to 16 feet. These improvements were practically completed in 1876.

Q. Then what was the next improvement made in the depth?

A. The next improvement was the removal of the bar at the mouth of Black River, at Port Huron.

Q. At what time was that?

A. Which was where the work was carried on between 1874 and 1879; and in 1876 the further improvement of the Lime Kiln Channel designed to give a depth of 20 feet of water was begun, which improvement was completed in 1891.

The 1876 enlargement contemplated a widening of the channel as well as deepening, and the work seems to have been carried on in a more or less desultory sort of way at first.

Q. In a general way, what proportion of the improvements have been made subsequently to 1890 and before, in those two rivers, the St. Clair and Detroit?

A. Well, something more than 20 times as much material

has been removed from the Detroit and St. Clair Rivers since 1890 as had been removed up to that time.

Mr. Wilkerson: What do you mean by "removed"?

A. Removed from its original place.

Q. And put in some other place in the river?

A. Put some place else; may have been put in the lake or the river.

Q. You mean the total quantity moved?

A. I mean the total quantity moved.

Q. Without regard to where it was put?

A. Without regard to where it was put.

Mr. Wilkerson: You have the figures on how much went back in the river at some other point?

Mr. Adcock: And how much washed out; yes, we have an exhibit on that which will show exactly.

Adjourned to 10:30 a. m. March 19, 1913.

March 19, 1913—10:30 a. m.

GARDNER S. WILLIAMS resumed the stand, testified further as follows:

Mr. Adcock: When was the United States Lake Survey established, Mr. Williams?

A. Well, the old original United States Lake Survey dates from somewhere in the 'fifties, I believe, and its work was substantially completed somewhere around the late 'seventies or 1880. The Lake Survey office was revived, I believe, about in the 'nineties. There was a period of a year or two, I think, when there was no work done under the Lake Survey, so-called; but the work of the Lake Survey was taken up again and appears prominently in the reports of the Chief of Engineers for the year 1900.

Q. What has been the scope of their work, briefly?

A. Primarily the purpose of the Lake Survey—

Q. I mean in the later years.

A. The same statement covers both. Primarily the purpose of the Lake Survey was to provide adequate information as to the channels, possibilities of navigation on the Great Lakes and their connecting waters; and the scope of this was extended to involve or include measurements of the outflow of the Great Lakes and the recording or the collection of observations of the elevations of water in the Great Lakes at various points. So that at the present time the scope of the Lake Sur-

vey work embraces practically everything in the way of hydrography of the Great Lakes; that is, the preparation of charts for navigators and charts for general information as to the depths and areas and contours of the Great Lakes, and also in regard to meteorological conditions, the discharge, and the rise and fall of the lakes and their connecting waters.

Q. The term "hydrography of the Great Lakes" has been used by you, also the word "hydraulics." Will you define those two, with reference to the Great Lakes?

A. The term hydrography is of kindred derivation to the word geography with which we are all familiar; geography being the depicting of the characteristics of the earth or of the land, and hydrography being the depicting of the characteristics of the water. Hydrography has been extended to include also questions of measurements of water flowing and so on, though originally the word was intended to cover simply the mapping of the conditions, or the representation of the conditions, examination into such conditions as would be shown upon a map, or described in some such way.

The term hydraulics is used to designate that branch of physical science which has to deal with the stability, equilibrium and motion of fluid bodies. As we apply it in this case, we confine it to the laws of the motion and equilibrium of water, leaving out the lighter fluids.

Q. What was the scope of the work of the International Waterways Commission, and the Board of Engineers on Deep Waterways?

A. The scope of the Board of Engineers on Deep Waterways was to investigate and report upon a plan for a deep waterway to connect the Great Lakes with the Atlantic Ocean. That report was made in furtherance of the earlier report of the so-called Deep Waterways Commission, which pointed out the possibilities of such a connection and the advantages which might accrue from it.

In connection with that work they also investigated and reported upon the feasibility of regulating the levels of the Great Lakes for the maintenance of deeper channels therein, by means particularly of a regulating dam or weir to be placed near or at the foot of Lake Erie.

The International Waterways Commission was appointed to further investigate the question of the regulation of the lakes, with particular reference to the international complications which might be involved, and among their instructions was that if they should find it advisable to regulate the levels of the lakes thereby involving international action, that

they should present a draft of a treaty to cover the points which would have to be adjusted between the United States and Canada.

The Commission had also various other matters appertaining to boundary waters referred to it, and was delayed for some time in taking up the matter of the regulation of Lake Erie; but in 1910 they published a report upon that subject which contains the computed discharges of all the outlets of the Great Lakes, and tabulated discharges of the St. Mary's, Detroit, Niagara and St. Lawrence Rivers. These discharges are based upon the observations for discharge which have been made under the direction or by the Lake Survey office and upon the records of lake elevations as recorded in that office. The assumptions and computations of discharge were, however, made entirely independent of the Lake Survey office, and are an independent deduction from the data obtained by the Lake Survey office. That report is known as the report upon the regulation of Lake Erie, report of the International Waterways Commission upon the regulation of Lake Erie, and is dated 1910.

Since the finishing of that report the Commission has been engaged in the demarcation of the international boundary line through the lakes, and upon some further studies upon the possibility of raising the level of Lake Erie by the construction of a dam elsewhere than at the foot of Lake Erie.

Q. You spoke of the regulation of Lake Erie. Will you state just what that work contemplated, its effect and so forth?

A. The original contemplation, which is due to a suggestion of the late Mr. George Y. Wisner, who was a member of the Board of Engineers on Deep Waterways, was to construct at the foot of Lake Erie a submerged dam, and a series of sluice gates, so that when Lake Erie was at a high stage the gates might be opened.

Mr. Wilkerson: Is this contained in some proceeding of the Commission?

Mr. Adcock: No, he is simply describing the regulation works as they were contemplated.

The Witness: So that when Lake Erie was high, or reached near the high water mark, the gates could be opened and additional water discharged, while as Lake Erie fell the gates would be closed, and with the obstruction which was provided by the submerged dam, the lake would be prevented from falling to its low water plane. This of course would maintain the lake at a more constant elevation, and at a

higher elevation than it has occupied on the average under the present conditions.

It was contemplated to regulate the surface of Lake Erie within average range of about two feet, if I remember correctly, and at a plane somewhat higher than the present low water plane; I think about two feet higher. The raising of the water of Lake Erie would reduce the fall in the Detroit River, thereby decreasing its discharge and raising Lake St. Clair, which in turn would decrease the fall in the St. Clair River and thereby raise Lake Huron, the effects being probably about one-half as much in St. Clair and about one-fourth as much in Lake Huron.

Mr. Wilkerson: Is this your conclusion or that of some one else?

A. It is mine; coincides with the Board's practically.

Mr. Adcock: When were discharge measurements made by the United States Lake Survey of the St. Clair River?

A. The earliest ones were made in the 'sixties, but they may be neglected, as the means by which they were made were so crude and the methods pursued were so inaccurate that although for many years they were the best we had and the only ones we had, they are to be entirely superseded by the results obtained from the later, more precise determinations or work of the Lake Survey, which began with the measurements of the St. Clair in 1899 and continued through 1902, and was taken up again in 1908 and continued through 1909 and 1910.

Q. How many discharge measurements were made, if you remember, in 1909 and 1902?

A. I don't think I can recall and I do not have the memoranda at hand. That has, however been testified to by the complainant's witnesses.

Q. For what period during each year did they cover?

A. In the main they covered the open season of navigation, although some measurements were made during the winter.

Q. That is on the St. Clair River?

A. On the St. Clair River.

Q. Where were those measurements made?

A. Those measurements were made at what is known or designated as the Section Dry Dock on the St. Clair River about five miles below the foot of Lake Huron.

Q. Can you designate on the map or chart entitled "St. Clair River," Williams' Exhibit 7, where that measurement was made?

A. Well, it was made in the vicinity of the legend "Reid

Wrecking Company Dry Dock Abandoned," which is found printed across the St. Clair River.

Q. Were there measurements made at any other place in the river during that period?

A. There were measurements made during the winter at a point further up stream, in fact within I think about a mile or less of the foot of Lake Huron.

Q. Do you remember what winter that was?

A. That was in the winter of 1900 and 1901, I believe.

Q. Were those measurements made at the same time that the measurements were made at the Dry Dock Section?

A. No, they were not simultaneous. There were measurements made at the Dry Dock Section during that winter, and then the party went from the Dry Dock Section to this upper section, and later returned to the Dry Dock.

Q. Were there any measurements made in the St. Clair River at the same time measurements were made in the Dry Dock Section?

A. No, there were no simultaneous measurements at two stations in the St. Clair River, so far as I have been able to discover.

Q. Was there a Gorge Section there, what they call the "Gorge Section"?

A. There is a section which has later been designated as the Gorge Section, which is about the narrowest section of the river and is about half a mile below the foot of the lake. Measurements were made at this section in 1908, 1909 and 1910, but no measurements were made there during the earlier period of gages.

Q. Were there any measurements made on the Niagara River?

A. (No answer.)

Mr. Wilkerson: These later measurements you have referred to were not before the International Waterways Commission, were they?

A. No, unless it is possible that the 1908 measurements may have been used.

Mr. Adcock: That is by the International?

A. By the International Waterways Commission. I don't know that they were, and I think it probable that they were not, but it is possible that they might have been.

Q. Were any measurements made of the discharge of the Niagara River by the United States Survey?

A. Yes, there were measurements made at the Niagara River by the United States Lake Survey at the request, first,

of the Board of Engineers on Deep Waterways, and subsequently additional measurements were made by the Lake Survey itself. Prior to these measurements, there had been some others made either by the Lake Survey or by the U. S. Engineer office at Buffalo, which appear to have been made in the early 'nineties. The reliable measurements, or the most reliable measurements of discharge of the Niagara River are, however, those made since 1899.

Q. Were they made during the period from 1899 to 1902, the measurements on the Niagara?

A. They began in September, 1898, and continued into 1900.

Q. Where were those measurements made, referring to Williams' Exhibit 12 entitled "Chart Buffalo Harbor"?

A. Those measurements were made from the International Bridge, so-called, which is about 2½ or 3 miles, say 3 miles, below the foot of Lake Erie, and also at another section in that vicinity about 2,000 feet further down stream.

Q. That was called what?

A. That was called the "Open Section", the former being designated as the "Bridge Section" in the records.

Q. They are designated on the map here, the first one is mentioned as International Bridge.

A. International Bridge; the location of the second one is near the foot of Squaw Island.

Q. Will you state how discharge measurements are made by the use of the current meter?

A. The process of measuring discharge by means of the current meter is, first, to make a measurement of a section, a cross-section of the stream to determine the area of the wetted portion, or the area of the body of water passing the point in question.

Points are then selected at intervals across the stream at which measurements are taken with the current meter, by lowering it from the surface to the bottom and occupying various positions as it passes down for a sufficient length of time to enable the meter to take up and repeat the velocity of the current. The number of points that are observed in a vertical, of course depends upon the degree of precision with which it is desired to get the changes of velocity from point to point. But common practice has been to make use of an observation at every tenth of the depth. The average velocity indicated by the meters at the several positions, when adjusted for difference of distance between successive positions,

if there be any, is taken as the mean velocity for that vertical, and a second or another vertical is observed in the same way.

In this way a series of readings of the velocity of the current is obtained at numerous points throughout the cross section, generally arranged in a series of vertical columns. The mean velocity of the vertical, when multiplied by the sum of half the areas between that vertical and the one next to it on either side is assumed to represent the velocity through that portion of the stream; or the mean velocities of the verticals may be plotted and a curve drawn through the observations indicating the total velocity which, when the mean ordinate of the area enclosed between this curve and the base is measured, gives the mean velocity of the water; and this in turn, when multiplied by the area of the cross section would give the discharge. For rapid gauging, it is customary after having examined the distribution of velocities through the vertical to select certain points which are called "index points" which bear a fixed relation to the average velocity of the vertical, so that in making a gauging of the stream, after the preliminary work has been done, it is only necessary to occupy one or two points in a vertical in order to get a measurement, instead of having to occupy all ten or more, as the case might be. In that case the measurement of the discharge of the river comprises the occupying of one or more points on each vertical across the stream, or if conditions warranted it, the number of verticals might be reduced, and certain controlling ones simply observed.

Q. Is it more difficult to measure the discharge of a large river than a small river?

A. Very much.

Q. Why is that?

A. Principally because of the difficulty of knowing what the condition of your measuring apparatus is. In a large river it is impossible to see it. In a small stream you can generally see the instrument and know in which way it is pointing, and whether there is any obstruction upon it, and what its condition is generally; whereas in a deep stream it is out of sight, and you can only judge by the information that is clicked to you through the telephone.

Q. Would that be true of a stream of the depth of the St. Clair River for instance, and Niagara?

A. Oh, yes, certainly.

Q. St. Lawrence?

A. There is a further difficulty in measuring in the deep stream as compared with a shallow one that whereas in the latter it is possible to hold the meter rigidly at a position by means of a rod, so that its position is exactly known, in the deep stream the meter has to be suspended upon a cord or cable or wire, and it then becomes a matter of some uncertainty as to just where the meter is, and in what direction it is pointing.

Mr. Wilkerson: I just wish to suggest that you have him define a little more definitely what you mean by the term "difficult", whether you mean difficult in the way of making the observation, or the possibility of a precise result after the difficulties are overcome?

Mr. Adcock: I will get to that in time.

Mr. Austrian: Just let him explain what he means by "difficult". You say "difficulty in measuring"? What do you mean by that?

A. I use that as applied to the difficulty of obtaining precise results. It also applies to the mechanical difficulties, the physical difficulties. It is very much easier to measure a small stream than it is a large one.

Mr. Adcock: Do you know how wide the St. Clair River is or was, at the time these gaugings were made at the Dry Dock Section and the Gorge Section?

A. The Dry Dock Section was somewhere in the neighborhood of 2500 feet, and the Gorge Section I think was about 1800 feet.

Q. How far apart were the verticals?

A. I think originally every 100 feet.

Q. In a river of the velocity of the St. Clair River, how often would the electric current make a break to indicate the revolutions of the current meter?

A. That would depend altogether on the type of meter used, and its rating. The revolutions per second will probably be about 2/3 of the velocity per second with the type of meters that were used, so that with a velocity of three feet a second, you would have about two revolutions per second or 120 a minute. And there would be a break at each revolution.

Q. And the way those 120 revolutions would be counted, would be by the ear, as we hear, the same way a doctor counts the pulse?

A. Yes. They do have recording devices, which record on a recording mechanism.

Mr. Wilkerson: How about the Lake Survey?

A. I think the Lake Survey has used the recording devices almost entirely, so that the counting is done mechanically.

Mr. Adcock: You mean it may be done mechanically?

A. It may be done mechanically and that was the practice.

Q. In the Lake Survey?

A. In the Lake Survey.

Q. Is the accuracy with which the current meter determines or records the velocity dependent in any way upon the rating of the meter?

A. Entirely. That is, that is the only means we have of knowing the number of revolutions of the meter wheel, which corresponds to any velocity.

Q. In a large river like the St. Clair, does the velocity change from time to time?

A. It does, very rapidly.

Q. Is the velocity in different portions of the river different?

A. It is.

Q. That is at different depths?

A. Both at different depths and at different points across the river.

Q. So the velocity at one-tenth depth or two-tenths depth to one vertical might change in how short a time if at all?

A. Why it would change somewhat in a few seconds. That is, it is vibrating, pulsating all the time.

Q. Would the current meter wheel be running continuously at a certain rate, or would there be pulsation or changes?

A. According to my own observation I never have found a current meter wheel to run regular in flowing water. There is always pulsation present.

Mr. Wilkerson: You are speaking now of two kinds of changes of velocity, one at a given point?

A. Yes.

Q. At the cross section; and the other as between the various points in the same cross section?

A. Yes, and my last statement refers to the changes at a certain point.

Mr. Wilkerson: At a certain point in the cross section. That is the one with reference to which he uses the term "pulsation"?

The Witness: Yes.

Mr. Adcock: Have you been present at the taking of the testimony of the complainant?

A. I was present at the taking of the testimony of all the witnesses of the complainant except Colonel Townsend and Mr. Coulby, and one day of Mr. Wheeler.

Q. You have read the testimony, have you not?

A. I have read the testimony of all the witnesses, and re-read that of several.

Mr. Adcock: These documents (referring to same) are the ones that were offered in evidence.

Mr. Wilkerson: If you have any papers that have been obtained from the Government records that you want to use, you may have them marked, offer them and use them in any way you please, for the purpose of this examination, providing that we reserve the right to check up on them and verify them to determine if they are inaccurate in any way, or if we conceive they are not complete to add to them such other portions of the record as we claim are essential to make them complete.

Mr. Adcock: There are certain records or measurements which offered, in evidence, by the complainant.

The Witness: No, they were not offered in evidence; they were identified at the request of the defendant.

Mr. Adcock: They were identified and they were the basis of those exhibits of yours, weren't they?

Mr. Wilkerson: There are some measurements which were produced by the Government in connection with the examination of the Government's expert witnesses. They were identified as the figures and tables upon which the computations of the Government's witnesses were based, and they were produced for inspection of the experts and counsel for the defendant, at their request. And they are here in this case to be used by both sides for whatever purposes they may be legitimately used in this case. They are not formally offered and they may be treated—

Mr. Adcock: As though they were in evidence?

Mr. Wilkerson: As if in evidence, at the hearing.

Mr. Adcock: They are in evidence now, and so that they may be identified, I will ask that the Commissioner mark them.

The Witness: They have been marked once.

Mr. Wilkerson: Are those all the tables we produced?

Mr. Adcock: I think so.

Mr. Wilkerson: Are you using all that we did produce?

A. Yes.

Q. And in addition to that you are using some other which you have since obtained?

A. In addition to that I am using some others I have since obtained.

Q. From the same source?

A. From the same source.

Q. As the ones which you produced?

A. (No response.)

Mr. Adcock: Referring to the records of measurements which Mr. Wilkerson has spoken about, I have here a paper entitled "United States Lake Survey, Discharge Measurements Dry Dock Section St. Clair River 1899 to 1900 to 1902"; also record of discharge measurements made in 1908, consisting of seven sheets, which will be marked Williams' Exhibit 21.

(Whereupon documents above referred to were marked by the Commissioner Williams' Exhibit 21.)

Mr. Adcock: This was identified by complainant's witness, Shenehon, in File 6, page 14, being page 472 of the continuously paged record.

I now submit to the Commissioner for identification (of the series of tabulations above referred to) seven sheets of tabulations, the first sheet being entitled "United States Lake Survey, Hydraulics of St. Clair River, mean slope for period November to December, 1908"; the second sheet being entitled "United States Lake Survey, Hydraulics of St. Clair River; Summary of Discharge Measurements Section Gorge, Sherman Moore, Junior, Engineer, April, 1909"; the third sheet being entitled "Hydraulics of St. Clair River, Summary of Discharge Measurements Section Dry Dock, Sherman Moore, Junior, Engineer, April 1909"; the fourth page being entitled "United States Lake Survey. Hydraulics of St. Clair River, Discharge of St. Clair River Section Gorge, Sherman Moore, Junior, Engineer, March, 1910"; the fifth sheet being entitled "United States Lake Survey. Hydraulics of St. Clair River; Discharge of St. Clair River Section Gorge, Sherman Moore, Junior, Engineer, March, 1910"; the sixth sheet being entitled "United States Lake Survey, Hydraulics of St. Clair River, Discharge of St. Clair River Section Dry Dock, Sherman Moore, Junior, Engineer, March, 1910;" and ask that all these be marked Williams' Exhibit 22, being a series of tabulations not heretofore identified in this case, but furnished by the United States Lake Survey.

(Tabulations above referred to were marked by the Commissioner Williams' Exhibit 22.)

Mr. Adcock: I hand to the Commissioner for identification a file of blue prints furnished by the Lake Survey office, each of which is marked "U. S. Lake Survey", and being tables comprising 37 sheets, the same being blue prints accompanying the report of Junior Engineer W. T. Richmond, on the hydraulics of the St. Clair River under date of April, 1911, not heretofore identified. To be marked Williams' Exhibit 23.

(The 37 sheets above referred to were marked by the Commissioner Williams' Exhibit 23.)

Mr. Adcock: I now submit to the Commissioner for identification a series of five sheets of records of discharge measurements entitled "Summary of Discharge Measurements International Bridge Section and Open Section of the Niagara River for the years 1898, 1899 and 1900", each sheet being identified by the signature of F. C. Shenehon, United States Assistant Engineer 1906. These sheets have been identified by complainant's witness Shenehon, and are of the series referred to by Mr. Wilkerson. I ask that they be marked Williams' Exhibit 24.

(The five sheets above referred to were marked by the Commissioner Williams' Exhibit 24.)

Mr. Adcock: I submit to the Commissioner for identification two sheets containing records of discharge measurements of the St. Lawrence River, each sheet being entitled "Summary of Discharges, Three Points Section," covering the discharge measurements in 1900 and 1901; the sheets being also identified by the signature of F. C. Shenehon, Assistant Engineer, May, 1906. These were identified by complaintant's witness Shenehon. I ask that they be marked Williams' Exhibit 25.

(The two sheets above referred to were marked by the Commissioner Williams' Exhibit 25.)

Mr. Adcock: I submit to the Commissioner for identification a group of six tables or six sheets of elevations of the Great Lakes as follows: Superior, at Superior, Wisconsin, and Marquette, Michigan; Michigan, at Milwaukee, Wisconsin; Huron at Harbor Beach, Michigan; St. Clair at St. Clair Flats Canal; Erie at Cleveland, Ohio; Ontario at Oswego, New York; being duplicates of Exhibits D, E, F, G, H and I for identification, identified by complainant's witness Shenehon, the same being extended from 1908 through 1912, fur-

nished by the office of the United States Lake Survey. The original of 1908 was identified by witness Shenehon. I ask that these be marked Williams' Exhibit 26.

(The six sheets above referred to were marked by the Commissioner Williams' Exhibit 26.)

Mr. Adcock: I now submit to the Commissioner for identification two sheets of tables furnished by the United States Lake Survey, one giving the mean monthly elevation of the Detroit River at Amherstburg, Ontario, and of Lake St. Clair at Windmill Point; and the second giving the mean monthly elevation of the Detroit River at Fort Wayne. These have not been heretofore identified. To be marked Williams' Exhibit 27.

(The two sheets above referred to were marked by the Commissioner Williams' Exhibit 27.)

Mr. Adcock: I now submit to the Commissioner for identification tables of mean daily elevations of water surface of Lakes St. Clair and Huron for selected periods, such tables having been furnished in conformity to a request of the United States District Attorney by the United States Lake Survey, and not heretofore identified. To be marked Williams' Exhibit 28.

(Tables above referred to were marked by the Commissioner Williams' Exhibit 28.)

Mr. Adcock: I now submit to the Commissioner for identification a series of tables embracing 17 typewritten pages and one blue print of daily mean gauge elevations for Lake Erie at various points for selected periods, furnished in conformity with the request of the United States District Attorney by the United States Lake Survey, and the United States engineer offices on Lake Erie. To be marked Williams' Exhibit 29.

(Tables above referred to were marked by the Commissioner Williams' Exhibit 29.)

Mr. Adcock: I now submit to the Commissioner for identification a series of tables consisting of five typewritten sheets representing the mean monthly elevations of Lake Ontario, Lake Erie and Lake Huron, and mean daily observations of Lake Ontario at Oswego and Ogdensburg for selected periods. These were furnished in response to a request of the United States District Attorney by the United States Lake Survey. To be marked Williams' Exhibit 30.

(Five typewritten sheets above referred to were marked by the Commissioner Williams' Exhibit 30.)

Mr. Adcock: I now submit to the Commissioner for identification a series of two sheets showing the mean monthly and annual rainfall in inches on the drainage areas of the Great Lakes, for a series of years terminating with 1906, having been furnished in response to a request of the United States District Attorney by the United States Lake Survey and not heretofore identified. To be marked Williams' Exhibit 31.

(The two sheets above referred to were marked by the Commissioner Williams' Exhibit 31.)

Mr. Adcock: I now submit to the Commissioner for identification pages 2855 to 2883, being appendix FFF2 of the annual report of the Chief of Engineers for 1903, with charts and tables, being the report upon the outflow rainfall and evaporation of the Valley of the Great Lakes, prepared by complainant's witness Wheeler and identified and referred to by him in his testimony in this case. To be marked Williams' Exhibit 32.

(Pages of Appendix FFF2 above referred to were marked by the Commissioner Williams' Exhibit 32.)

Mr. Adcock: I now submit to the Commissioner for identification pages 90, 91 and 92 of the water levels of Lake St. Clair, to be marked Exhibits 33 A, B and C respectively; page 94, the water levels of Lake Erie at Buffalo breakwater to be marked Exhibits 33D; page 95, water levels of Lake Ontario at Charlotte, to be marked Exhibit 33E; page 101 of the discharge from Lake Superior to be marked Exhibit 33F; page 102 on the discharge from Lake Huron-Michigan to be marked 33G; page 103 of the discharge from Lake Erie from the Report of the International Waterways Commission on regulation of Lake Erie under date of 1910 to be marked 33H; page 104, discharge from Lake Ontario to be marked Exhibit 33I.

(The pages above referred to were marked by the Commissioner as already indicated.)

Recess to 1:30 P. M.

After recess—1:30 P. M.

GARDNER S. WILLIAMS, resumed the stand, and testified further as follows:

Mr. Adcock: Since the institution of this suit, Mr. Williams, have you made any further study than you have mentioned heretofore with reference to the hydraulics and hydrography of the Great Lakes?

A. I have made a very careful study of the evidence presented by the complainant, and of tables of reduced data, which have been furnished to me through the courtesy of the complainant, being derived from the original sources upon which complainant's testimony in regard to the discharge and effects upon lake elevations is based.

Q. Have you made any particular studies and deductions from the records of discharge measurements made on the St. Clair River, the Niagara River and the St. Lawrence River, which have been referred to?

A. I have.

Q. I show you here Williams' Exhibit 21 referring to discharge measurements Dry Dock Section St. Clair for certain years, and ask you to state in a general way what is shown by that exhibit?

A. This exhibit shows the record for the several gaugings of the St. Clair River between 1899 and 1908, exclusive of those made during the ice season and indicates the consecutive number of the measurement, the date of the measurement, the elevation of the water surface of Lake Huron at the time of the measurement, the elevation of the water surface at St. Clair Flats at the time of the measurement, the fall from Lake Huron to St. Clair Flats at the time of the measurement, the direction and velocity of the wind at the time of the measurement, and the discharge; and also arranged in groups of ten observations at similar stages, the stages being based upon the elevation of Lake Huron, the mean elevation of Lake Huron for the several observations in each group, the mean elevation of St. Clair Flats, the mean fall from Lake Huron to St. Clair Flats, and the mean discharge in cubic feet per second.

Mr. Shenehon: How many in each group?

The Witness: I said there were 10 in general. There are 10 in all groups of the observations for 1899, 1900 and 1902; and these groups are indicated by the letters from *A* to *U*

inclusive, there being 10 in all groups from *A* to *T* inclusive, and four observations in group *U*. These groups are also indicated by number, from 1 to 21, group 21 being that having but four observations. In the observations for 1901 there are four groups, Groups 1, 2 and 3, which are also designated as *V*, *W* and *X*, containing 10 observations each and Group 4, which is designated also as *Y* contains six observations

In the observations for 1908 there are two groups, one designated Group 1 or *Z*, which contains seven observations, and one designated Group 2 or Alpha, which contains eight observations.

Q. The elevation of Lake Huron is referred to there. Do you know at what point the gauging was made?

A. The elevation of Lake Huron referred to is understood by me from the testimony of the complainant to be at Harbor Beach. It has been my understanding that it is Harbor Beach.

Q. Do you know how the elevation indicated there, the Harbor Beach gauge, was derived?

A. It was not observed simultaneously with the discharge measurements in all cases. It might have been in some. Where it was not observed, it was derived from a gauge relation, first, between the gauge at the Grand Trunk Railroad Dock and Fort Gratiot, and then by a relation from Port Gratiot to Harbor Beach.

Q. Will you indicate on Williams Exhibit 7, Discharge of St. Clair River, where the Grand Trunk gauge is located, and the Fort Gratiot gauge?

A. (Referring to Exhibit 7) The Grand Trunk gauge is located within a mile of the foot of Lake Huron; I think a little less than a mile. The Fort Gratiot gauge is practically at the foot of Lake Huron, and is indicated on this chart by the legend "Fort Gratiot Light and Fog Whistle". The Harbor Beach gauge is some 60 miles I think up Lake Huron.

Q. Do you know when the Grand Trunk Gauge was read with reference to the time when the observation was made?

A. It was read I believe simultaneously—or continuously during the periods of observation, at frequent intervals, and through part of the observations I think a self-registering gauge was used there.

Q. When you speak of getting the Harbor Beach gauge from the relation between that and Fort Gratiot and Grand Trunk, just state how that was done.

A. Simultaneous observations of the water stage are

taken at two of the gauges in question, and by the relation thereby established from one to the other, the reading of one gauge or the mean reading of one gauge corresponding to the mean reading of the other is established, and that correction is then applied to the readings of one to get the reading of the other.

Of course it may be found that there is no mean correction, but that there is a change depending upon the change of elevation of the lake surfaces, in which case where the law of the change can be established, the corrections are made in accordance with that law; the difference possibly being greater for high elevations than it is for low ones.

Q. Do you know how long a time it took to make one gauging on the river at the Dry Dock Section, say?

A. As I remember the complainant's testimony it was about three hours.

Q. Have you made any study of the records of the observations in the three rivers which I have mentioned, or have you made any calculations to determine the accuracy or inaccacuracy of the observations and the results reached by the complainant?

A. I have so far as it has seemed to be possible from the information that has been at my disposal.

Q. Have you made any examination of the records of the observations, measurements and with reference to lake stage and so forth?

A. I have.

Q. I will ask you in a general way if the records of the measurements, discharge measurements of the Niagara and St. Lawrence Rivers are arranged in substantially the same manner as the records of the discharge measurements of the St. Clair?

A. They contain the similar information as to lake stage or lake elevation and discharge, wind. Of course in these observations there is no question of a gauge below the station, that is of another lake being involved other than the one at the head. Nevertheless the elevations of the lake, and of the gauge at the gauging section are given in these tabulations, and the observations are not grouped as the observations on the St. Clair, but this tabulation simply shows them in chronological order on the St. Lawrence and on the Niagara River, both.

Q. Based upon the records of these discharge measurements that have just been referred to, and upon the facts

which have been stated by the complainant's witnesses, have you reached any conclusions, or do you find any indications which would tend to determine the accuracy or inaccuracy of the observations made and the results reached by the complainant from such observations?

A. I do.

Q. I show you, Mr. Williams, certain tables, being marked 1 to 54 inclusive, and plates from 1 to 8 inclusive following in numerical order, and ask you to state what they are? They may be marked Exhibit 34, being Tables 1 to 54 and Plates 1 to 8, and I will ask you to state what that exhibit contains.

(The documents above referred to were marked by the Commissioner Williams' Exhibit 34.)

A. That exhibit embraces the computations or the reduced computations which I have made in determining the hydraulic questions which seem to me to be involved in this case.

Tables 1 to 17 inclusive deal with the examination of the precision of the Complainant's observations. Tables 18, 19, and 21 present the elevations of the water surfaces of the Great Lakes, Huron, St. Clair and Erie, and the falls between them and the relation of the fluctuations or changes of annual elevation of these lakes.

Tables 22 to 39 deal with the derivation of the increments of the St. Clair River.

Table 40 is a computation of the discharge of the St. Clair River from 1900 to 1907 by the use of the equations or the equation derived from the preceding tables.

Tables 41 to 43 deal with the increment and the discharge of the St. Lawrence River.

Table 44 deals with the fluctuation or annual change of stage of Lakes Erie and Ontario.

Tables 45 to 47 deal with the increment of the Niagara River.

Table 48 presents an estimated rainfall upon the drainage areas of the several lakes, based upon the rainfall records for Lake Superior at Marquette, for Lakes Michigan-Huron at Milwaukee and Detroit; for Erie and St. Clair at Detroit, Cleveland and Buffalo, for Ontario at Buffalo, Oswego, Rochester and Toronto.

Tables 49 and 50 present the average annual elevation of Lake Ontario and of Lake Superior; and Table 51 is a summary of the annual elevations and differences of elevation from lake to lake of Lakes Superior, Michigan-Huron, St. Clair, Erie and Ontario.

Table 52 is a further summary of similar information.

Table 53 represents the amount of material that has been dredged from the channels of the St. Clair River, from Lake St. Clair and the Detroit River, from 1870 to 1910, inclusive.

Table 54 presents the relative change of annual stage of Lakes Erie and St. Clair.

Plate 1 is a reproduction as accurately as it was possible to reproduce it by the services of an accurate draftsman of Complainant's Exhibit 1; the purpose of the reproduction being to get it to a size which would be convenient for reference in connection with the other data presented in these tables.

Plate 2 is a similar reproduction of Complainant's Exhibit 2. Plate 3 is a similar reproduction of Complainant's Exhibit 3. Plate 4 is a similar reproduction of Complainant's Exhibit 4.

Plate 5 is a representation of the increment for the St. Clair River as derived by the methods indicated in the reductions made by myself.

Plate 6 is a similar representation of the increment of the St. Lawrence, as similarly derived.

Plate 7 is a photographic reproduction of a portion of the chart of the head of the St. Clair River, said chart being one obtained by me from the United States Lake Survey office about 1897, which is stamped with the legend "Aids to Navigation corrected from information received to April 20th, 1892." To this chart has been added by me two parallel lines at the head of the river enclosing Fort Gratiot.

Plate 8 is from a chart of the same river, a duplicate of the one placed in evidence as Williams' Exhibit 7, which was obtained from the United States Lake Survey office in February, 1913, and by its stamp purports to be corrected to "December 26th, 1912."

On this chart there has also been drawn two parallel lines enclosing Fort Gratiot, which I believe to be in a position corresponding to those drawn on Plate 7.

Q. From what data and information were these tables compiled?

A. With the exception of Table 48 of precipitation, Table 53 on dredging, they have all been derived from the original tables furnished by the complainant through the office of the United States Lake Survey, or from one or two of the other United States engineers' offices along the Great Lakes, which were in possession of special information which had not at that time been transmitted to the Lake Survey office.

The table of estimated precipitation, Table 48, is made up from the published information in regard to precipitation which is to be found in the records of Government observations, including those which were collected by the Smithsonian Institution; those which were obtained while the Weather Service was under the United States Army, and those more accurate ones which have been presented by the work of the United States Weather Bureau as latterly constituted.

Table 53 showing the quantities of material dredged from the several channels of the St. Clair River, Lake St. Clair and the Detroit River has been compiled from the published reports of the Engineer Officers in charge of the River and Harbor District in which this work has been carried on, as presented in the annual reports of the Chief of Engineers of the United States Army from 1870 to date.

As to the plates, as already said, Plates 1, 2, 3 and 4 are copies of the exhibits of the complainant. Plates 5 and 6 are graphical representations of my own computations. Plates 7 and 8 are photographs of charts published by the United States Lake Survey, with the addition of two parallel lines for the purpose of indicating a particular locality.

Q. Were the computations as represented upon the tables correctly made?

A. To the best of my knowledge, belief and ability and that of my office.

Mr. Wilkerson: How much did you do personally?

A. I outlined practically every table; made preliminary computations of most of them; checked the computations of nearly all, and have watched the construction of every one of them from the time the first pencil mark was made until it was finished, and had received a third or fourth check.

I have devoted a considerable part of the last four years to doing it.

Mr. Adcock: The computations that you have arrived at, and the conclusions you have reached are based upon the series of tables heretofore identified by you, and the facts and circumstances testified to by Complainant's witnesses and the documents identified by them, already in evidence?

A. They are.

Q. Will you state your conclusions as to the accuracy or inaccuracy of the observations made and the results reached by the complainant, taking it up by the different subjects; and also state the basis upon which you reach your conclusions;

and also the method which you have used in arriving at your conclusions?

Mr. Wilkerson: I will not interrupt the witness while he is making this statement, with reference to an explanation of these tables, but I reserve the right in the future to move to strike out of the testimony any statements of the witness which I deem to be statements of an improper conclusion, or which I regard as otherwise incompetent, irrevelant and immaterial.

Mr. Adcock: That is when the statement is concluded, or at some reasonable time afterwards.

Mr. Wilkerson: Yes, after we have had an opportunity to consider it.

Mr. Austrian: So as to give us an opportunity to recall him.

Mr. Wilkerson: Undoubtedly, before his testimony is finished I will concede it to be my duty to indicate to you any such motion as I may have, so that you will have an opportunity to recall the witness and put to him such questions as you conceive to be proper to cover the objectionable matter, if it be manifest it is objectionable from a legal standpoint.

A. The accuracy of the observations on discharge appears from a comparison of observations made at each place, and a comparison of observations made at two places on the Niagara and on the St. Clair Rivers to be equal to that of any similar series of observations known.

However, certain inconsistencies, as will be hereafter shown, appear between the results on the Niagara and those on the other two rivers. But even granting the highest degree of accuracy indicated, the magnitudes measured are so great that the differences due to the diversion considered in this case are too small to be the subject of direct measurement.

On the St. Clair River there are 33 observations referred to the Harbor Beach gauge, in which the reported elevations of Huron and St. Clair were repeated in two or more, giving 21 observations of discharge measured under the same observed conditions, as to the two locations; and these are presented in Table 1 of Exhibit 34. The variations of these discharges range from 600 to 8,600 cubic feet per second, with a mean of 3,305; or the maximum difference is 2.22 per cent., the minimum .15 of one per cent., and the average variation from the mean is .844 of one per cent. of the average discharges.

Mr. Austrian: What do you mean by "mean"?

A. I take the mean discharge of the whole series, and the mean variation.

Q. By that you mean average?

A. The average variation from the mean would be one-half of the mean variation; that is, assuming that the variation is above and below, so that the average from the mean would be one-half of the mean variation.

Taking the Grand Trunk gauge instead of that of Harbor Beach, there are 33 observations giving 18 comparisons shown in Table 2; of which the maximum variation is 8,600, the minimum 400 and the mean 3,350 cubic feet per second. And giving the maximum difference as 2.14 per cent., the minimum as 0.104 of one per cent. and the average variation from the mean .831 of one per cent. of the average discharges.

On the Niagara River at the Bridge Section are 40 observations giving comparisons of two or more with the same stage reported for Lake Erie and shown in Table 3, and from these 23 comparisons are obtained giving a variation ranging from zero to 21,600 cubic feet per second, with an average of 4,578 cubic feet per second. The maximum difference is 5.27 per cent., the minimum, zero; the average variation from the mean 1.202 per cent. of the average discharges.

On the Niagara River at the Open Section there are 54 observations at the same stage of Lake Erie shown in Table 4, giving 29 comparisons, with differences ranging from zero to 7,800 cubic feet per second, and a mean variation of 2,962 cubic feet per second. The maximum difference is 2.007 per cent., the minimum zero, and the average variation from the mean .79 of one per cent. of the average discharges.

On the St. Lawrence River, the discharges refer to the gauge at Ogdensburg, and does not include the full fluctuations of Lake Ontario. The gauge location is over 60 miles from the lake and the gauging station some 15 miles further. There are 51 comparable observations which are shown in Table 5 giving 36 differences ranging from zero to 4,200 cubic feet per second, with an average of 1792. The maximum difference is .844 of one per cent.; the minimum, zero, and the average variation from the mean .37 of one per cent. of the average discharges.

If these last gaugings were referred to the actual simultaneous elevations of Lake Ontario, it is improbable that they would show a degree of accuracy above those on the St. Clair River, there being an advantage so far as the gaugings are concerned in the reference to the near-by gauge.

A comparison of the St. Clair gaugings is shown in Tables 6 and 7, based upon the gaugings in 1908, 1909 and 1910, a part of them being at the original or Dry Dock Section, and a part

of them at the Gorge Section of the St. Clair River. The Dry Dock Section is below and the Gorge Section above the mouth of Black River, which probably contributed from 100 to 200 cubic feet per second to the flow of the river.

On account of the Lakes Huron and St. Clair being alike involved—

Mr. Adcock: Just a moment: On those Tables, 1 to 5 inclusive, at the top there are numbers stated. What are those figures underneath there, what do they indicate?

A. Those are the numbers of the experiment as numbered in the records of the complainant.

Q. When you say "experiment" you mean of the observation?

A. Of the observation as numbered in the records of the complainant corresponding to the numbers in the first column on Williams' Exhibit 21.

The second column gives the elevation of Lake Huron, as given in the third column of Exhibit 21.

Mr. Wilkerson: You are speaking of Table 6?

A. Table 1.

Mr. Adcock: All the rest are in the same way.

A. Column 3 headed "St. Clair elevation" corresponds to the fourth column of Exhibit 21.

The fourth column headed "Discharge" corresponds to the last column of Exhibit 21. The column headed "Difference" is the difference between the two discharges which is seen in the fourth column; and the percent variation from mean is the percentage which this difference is of the mean discharge of the two measurements considered.

Q. Then they are arranged in groups, where Huron and St. Clair were at the same elevation, is that right?

A. Yes, sir, and are arranged in order of elevation of Lake St. Clair.

Q. So that if the observations should indicate the exact discharge, they ought to be the same in each group, ought they not?

A. That would be expected if there were no conditions which are unaccounted for in the discharge.

Q. That is, you have the elevation of the lake the same?

A. The elevation of the two lakes the same.

Q. The two lakes being the same?

A. The slope of the river, the fall of the river is the same.

Q. Why do you take Huron and St. Clair at the same elevations?

A. Because both lakes affect the discharge of the St. Clair River, and it would not be proper to consider only one of them, as the variation in position of the other would influence the discharge.

Q. Will you indicate just how that would affect the discharge, that is, the raising of St. Clair?

A. If St. Clair were to rise, it would decrease the fall between Huron and St. Clair. The flow in the river is dependent upon this fall to overcome the resistancies which are encountered in the motion of the water, so that if the fall be decreased, the forces which are to overcome the resistencies are decreased, and the discharge is reduced.

Q. And the velocity is decreased?

A. The velocity is reduced, and the change of velocity is greater than the change in section which may result from the raising of the lower part of the river.

Q. That is the area of the cross-section?

A. That is the area of the cross-section is increased by the raising of Lake St. Clair, but the change in velocity is greater in proportion, so that the net result is a reduction in the discharge.

Q. Now will you continue your answer to the general question?

Mr. Wilkerson: In regard to this first table, take this Table 1, take the fifth line, Huron elevation?

A. St. Clair elevation is 575.36; the ditto marks have not been put in, but the St. Clair elevation appears until it is changed in the column.

Q. There is a difference there of 6,000?

A. Yes.

Q. As to those two particular observations. Might the fact that one observation was made when the river was in the rising stage and another when it was in the falling stage, might that factor account for that difference?

A. It would very likely account for it, and that is one of sources of inaccuracy of current meter gaugings.

Q. But in a long series of observations, the river being in a rising stage about as often as it is fallen, that will be eliminated to a much greater extent than if you compared two observations?

A. Certainly.

Q. That is the thought I had in mind, that I wanted to get clear.

A. Or stated another way, the average of a large number

of results will be more accurate than the average of a small number of results.

Q. Then the comparison of two?

A. Assuming them to be taken under general conditions.

Continuing the comparison of the St. Clair observations, on account of Lakes Huron and St. Clair, both being involved, it is difficult to find observations at each section when both were at the same elevation, but some instances of the kind are shown in the lower half of Table 7. In four of the six cases presented—

Mr. Wilkerson: By the lower part, you mean commencing with which line?

A. I mean in the lower portion of the table. There are two tables on 7, one marked "By Single Observations."

Q. The one headed "By Single Observations?"

A. Yes, the one headed "By Single Observations."

In four of the six cases presented there was a difference of .01 in the elevation of Lake St. Clair, and in one a similar difference in that of Huron. These differences have been corrected by the values for the separate increments computed in Table 24. The observed differences for similar conditions when so corrected at the two sections range from 380 to 2,410 cubic feet per second. If the corrections had not been made, the difference would still remain at approximately the same figures. The corrections are indicated in this sixth column.

In the upper part of Table 7 is presented the comparison of the groups of observations which have been assembled in Table 6; corrections of variations of either lake being made as in the previously considered case.

Then in Table 6, I have given the individual observations which are considered at each location, and we have taken the means of these several groups to make the comparison that is presented in the upper portion of Table 7. The differences here range from 140 to 4,172 cubic feet per second; the mean being 1,851 cubic feet per second. The maximum difference is 2.24 per cent., the minimum .75 of one per cent. and the mean less than one per cent. of the average discharges.

Further evidence of the accuracy of discharge measurements of the St. Clair River is to be found in a comparison of Tables 24, 31 and 33, showing the results of the 1899 and 1902 gaugings, with Tables 27, 37 and 39 of the 1908 and 1910 gaugings. The observations of the earlier table were in general at higher stages than the later ones, so that the center of gravity of the lower half in Table 33 is at very nearly the same

elevation as the center of gravity of the upper half of Table 39.

Mr. Adcock: What do you mean by the center of gravity?

A. The observations of these tables are divided into two groups, first the center of gravity, or the mean point or the mean of both lake stage and the discharge is taken. This divides the observations into two groups, and the mean point or centers of gravity of the upper portion and the lower portion are then taken. This gives three points on the straight line, which most nearly represent the observations that are included.

Q. Is that a well known method of getting at the correct, true line showing the center of gravity of all the observations?

A. That is the mathematically accurate method of deriving the straight line which most nearly fits a series of points.

Q. Is that a line such as is referred to in Complainant's Exhibits 1 to 4 inclusive?

A. It is the line which the complainant was endeavoring to locate, by a purely ocular method of stretching a string across his observations. It might have been mathematically computed by the process which has been indicated here, and which I may say is based upon the well known theory of moments in mechanics.

Q. How did they get their line?

A. The points were plotted and a string was stretched across the plotting and adjusted by the eye until it seemed to fit most nearly the position of the points.

Q. Will you continue the answer?

A. By the former table, Table 33, a stage of 580.404 of Lake Huron corresponded to a discharge of 189,064 cubic feet per second, and the increment was 28,872.

By the latter table, Table 39, a stage of 580.460 of Lake Huron corresponds to a discharge of 191,591 cubic feet per second. The difference between 580.460 and 580.404 is .056 foot, and the increase in discharge due to this increased stage by Table 33 would be 28,872 times .056, equals 1,617 cubic feet per second, which added to the discharge at 580.404 gives 189,064 plus 1,617 equals 190,681 as the discharge by the 1899 to 1902 gagings corresponding to the elevation at which a discharge of 191,591 cubic feet per second was found in 1908 to 1910; thus showing a difference in observed discharged capacity of 910 cubic feet per second, or less than one-half of one per cent.

In view of the fact that during these later observations the Detroit River was obstructed by the Livingstone Channel cof-

fer dam, which is stated to have raised the water above it about 2 inches, thus decreasing the flow, it is interesting to note that the later measurements show the larger discharge.

Q. You say it is stated to have raised the water about two inches? That is from gauge records which you have?

A. That is shown by gauge records which I have, but was stated by Colonel Mason M. Patrick upon oath on the witness stand before the International Joint Commission at a hearing in Detroit within the past month in my presence.

Q. Who is Colonel Patrick?

A. He is the engineer officer in charge of the river improvements on the Detroit River at the present time, located at Detroit.

Mr. Austrian: He is a government officer?

A. He is a United States engineer officer.

Mr. Adcock: If there is any question about that fact as to the raising there of two inches on account of the coffer dam, if you let us know, we will verify it by some other method.

Mr. Wilkerson: We will check the statement. If there is any question we will let you know so that you can make your proof in your own way.

The Witness: For the Niagara River, Table 8 shows a comparison of the gagings at the Bridge and Open Sections, the comparison being made between the mean results at the several stages.

For 1899, the observations show a maximum positive difference of plus 1.03 per cent. and a maximum negative difference of minus 9.06 per cent. of the average discharge, with the Bridge Section positive; the Open Section discharge being the greater in seven out of nine comparisons.

Q. What do those negative and positive quantities mean?

A. I considered the bridge section as being a positive quantity and subtracted the discharge of the Open Section from it, so that if the Open Section discharge were greater than the discharge of the Bridge Section my result would be negative.

Q. That is you arbitrarily in this Table 8——

A. I arbitrarily subtracted the Open Section from the Bridge Section in each case and gave the result the algebraic sign.

Q. And indicated the Bridge Section positive and the Open Section Negative?

A. Yes. Combining the 1898 and 1899 observations in Table 9, we get the maximum positive difference as 3.75 per

cent., the maximum negative difference minus 2.06 per cent.; the bridge section being positive as before. In this comparison, the Bridge Section shows the higher discharges in 21, and the open section in four cases.

Combining the 1898 and the 1900 observations in Table 10, the maximum positive difference is 4.5 per cent., the maximum negative difference is 0.3 per cent. The Bridge Section shows the higher discharge eight times and the Open Section once.

Combining the 1899 and 1900 work in the bottom of Table 10, there is no positive variation, the difference being all negative and ranging from minus 7.5 per cent. to 1.58 per cent. It will be seen by comparing these results with those on the St. Clair that the agreement of these observations is only about half as close as those in the St. Clair River.

If we compute the discharge of the Niagara River from the monthly mean stages of Lake Erie at Buffalo, by the equations derived by the complainant, which computations are shown on Tables 11 and 12, from 1900 to 1907, inclusive, we have an average discharge at the Bridge Section, by the equation derived from the Bridge Section observations of 201,436 cubic feet per second, and at the Open Section of 198,708 cubic feet per second, a difference of 2,728 cubic feet, or 1.36 per cent. of the mean.

Q. When you say "by the equations derived by the complainant," what do you mean?

A. I mean by the use of the increments which the complainant has introduced in its testimony in this case, the increment being applied for an elevation of 571, with a discharge of 175,000 cubic feet per second in the case of the Bridge Section, and for the same elevation with a discharge of 172,600 cubic feet per second in the case of the Open Section.

Q. That was for the Niagara River?

A. Yes. I should state that the elevations of Lake Erie at the Buffalo gage have been derived from the report of the International Waterways Commission on the regulation of Lake Erie for 1910, being marked Williams Exhibit 33D.

Considering the relative reliability of the several sources of observations, the observations on the St. Clair River cover periods in five different years for the original group, and two additional years for the subsequent group, while those at the Niagara are confined to three years, and those on the St. Lawrence to two years.

The observations on the St. Clair, as testified to by the complainant, have covered a range of stage from 579.65 to

581.39 approximately; on the Niagara from 570.00 to 573.92 at the Bridge Section and 570.67 to 573.41 at the Open Section, approximately. And on the St. Lawrence from elevation 242.85 to 245.28 approximately.

From 1890 to 1907, inclusive, Lake Huron at Harbor Beach has ranged in monthly mean elevation from 579.02 to 581.71; Lake Erie at Buffalo from 570.79 to 573.92, and Lake Ontario at Ogdensburg from 242.66 to 246.82.

The method of gaging and the location of the section on the St. Clair River leads me to expect more reliable results than on either of the other rivers, and the range of stage covered relatively to the lake fluctuations give a larger proportion of the lake variations included than on the St. Lawrence, the former covering 65 per cent. and the latter 58 per cent. of the lake range.

Q. Just what do you mean, with reference to that latter statement, as to the range of stage?

A. That the actual observations covered a larger percentage of the rise and fall of the lake, of the space passed over by the lake in its natural rise and fall by monthly means in the case of the St. Clair than it did cover in the case of the St. Lawrence, and of course the greater range that you cover with your observations, the more accurately can you determine the relation of changes of elevation to the discharge, assuming the same degree of accuracy in both sets of observations.

Q. Well, is it necessary in order to get accurate results from the discharges of rivers in determining the increment, that the observations cover the range of stage of the lake normally?

A. Well, it is not necessary that they should cover the entire range, but the more nearly they cover it, the more accurately the increment is determined. That is the greater the range between the high and low points of the lake in the observations used for the determination of the increment, assuming equal accuracy for all observations, the more accurately would the increment be determined.

Gagings of the St. Lawrence River from the Bridge at Valley Field, with which I was associated in 1909, give a discharge about 5 per cent. higher than would be indicated by the United States Lake Survey measurements when corrected for the added drainage area.

From all the foregoing, it is my conclusion that the St. Clair gagings as representing changes of discharge due to varia-

tions of lake level are intrinsically more accurate than those of Niagara, and, when the location of the reference gage is considered, more accurate than those of the St. Lawrence. The close coincidence of the 1899 to the 1902 results with those of 1908, 1909 and 1910, and the proved close coincidence of the latter, by the Dry Dock and Gorge comparisons, establishes in my mind beyond question the rank of the St. Clair measurements as the first among those considered.

It however appears that with all their care, experience and scientific apparatus, which I may say I believe has not been exceeded in any series of similar observations that have ever been undertaken, the government engineers by the complainant's method of deduction, are unable to detect variations of 3,000 to 4,000 cubic feet per second in the discharge of the St. Clair and Niagara Rivers; and by their discharge equations for the Niagara, there is a difference of nearly 3,000 cubic feet per second in the average discharge of eight years.

Q. Mr. Williams, in the measurement of the discharge of large rivers like the St. Clair, St. Lawrence and the Niagara, is there anything to which you can tie the observations of the discharge, from which you can determine the accuracy or inaccuracy of the measurements.

A. No, there is nothing outside of the measurements themselves. Of course we could detect an inconsistent observation, as one, for instance, that might show a larger discharge for a lower stage of the lake, we would say on the face of it that was wrong, but that would be on the evidence of the observations themselves. There is nothing outside of the observations to which you can tie them to determine their accuracy.

Q. Take for instance, a case where observations were made 1896 under the conditions, natural conditions which existed, showing a certain discharge of the river, certain volume; then suppose that in 1900 a diversion at some other point than the ordinary outlet had been made of 10,000 to 14,000 cubic feet of water per second; and suppose that, say in the year 1907, under natural conditions, you then make a series of discharge observations, would you be able to detect from the observations made in 1896 or observations made in the latter period in 1907, the obstruction or diversion of water at some other point.

Mr. Wilkerson: I object to that. It is a hypothetical question and does not pretend to include all the elements to be considered in this case.

A. You would not. I just want to correct that answer. I

understand that this question applies to measurements in any of the rivers that are outlets of the Great Lakes, and that the quantity involved is that mentioned near the beginning of the inquiry, from 10,000 to 14,000 cubic feet per second.

Q. Yes.

A. My answer is no.

Q. Will you state your reasons why you could not?

A. Because there are so many other conditions which enter in to affect the outflow of the lakes that having simply the gagings at the two periods, if nothing were known of this diversion by the parties making the gagings, they would be unable,—they would not be able in their gagings to find anything that would lead them to even suspect that such a diversion were taking place, because of the uncertainty of the large number of other factors that enter in, particularly rainfall and evaporation and the effects of ice.

Mr. Wilkerson: Suppose the other factors all remained fixed, could you tell it?

A. If they had all remained fixed, it could be told, not in its full magnitude, but that there was a diversion.

Mr. Adcock: You could not tell how much?

A. Not accurately. A diversion of the amount, of 10,000 cubic feet, would be detected in the measurement if all other conditions had remained the same during the periods intervening.

Q. Would you be likely to find the conditions, all conditions the same in two periods of measurements?

A. It would be about as easy as to find two leaves alike on a tree.

Q. Now, Mr. Williams, have you made any computations and calculations as to the increments, or have you derived any increments from the discharge measurements of the St. Clair, Niagara and St. Lawrence Rivers?

A. I have.

Q. Will you state what increments you have derived, how you have derived them, and the methods used in making your derivations?

A. I first examined the increments as derived or as presented by the complainant in his Exhibits 1, 2, 3 and 4, with a view to ascertaining the accuracy with which those increments had been derived from the data which had been used. I then investigated to see what would be the effect upon the increments had data which the complainant did not include in his derivation been introduced, introducing separately the

gagings of 1908 and 1901, first as corrected by the complainant, and second as actually observed.

Those computations are indicated upon tables 13, 14 and 15. Table 13 represents the computations, or the results of the computations for determining the increment upon the principle which was attempted to be applied by the complainant in the derivation of its increment in Complainant's Exhibit 1, and is based upon the observations of 1899, 1900 and 1902; the observations of 1901 having been neglected, upon the assumed ground that they do not represent normal conditions, and the observations of 1908 having been received too late to have been included in the computation at the time it was made, if I understand the circumstances correctly.

Applying the mathematical method of determining the three centers of gravity of the whole group and the two divisions of the group into which the center of gravity of the whole divides it, we find that the increment as represented by observations from *A* to *U*, giving each equal weight, would be 24,157 cubic feet per second as compared with the complainant's rough and ready determination, or approximate determination, by means of stretching a string of 23,820.

Q. The groups *A* to *U* inclusive, are those the groups of observations which the complainant used?

A. They are the groups of observations shown on Williams' Exhibit 21, which were used by the complainant and are indicated by the letters on this Exhibit 1.

Q. Is the line shown on chart, plate—

A. Plate 1 shows the complainant's line, the line of these observations—this reduction has not been put upon that chart.

Q. And plate 5?

Mr. Wilkerson: Q. There would not be very much difference?

A. No, it is only about 1½ per cent.

Q. That is, if you draw the line on plate 1, the lines are pretty near together?

A. The top of it would be a little bit lower than the line that is drawn there. I must say that as a piece of work of stretching a string, it was an excellent job of stretching.

Mr. Adcock: Q. And does plate 5 show the line which you have—

A. No, it does not. That refers to another determination of an increment to which we will come later on.

By a similar examination of the data, including the obser-

vations of 1908 which are presented in table 14, I find that had this data all been included and the observations given equal weight and the line mathematically determined, the increment would have been about 3½ per cent. higher than the value appearing on the complainant's chart.

Q. How does that table differ from table 13?

A. By the introduction of the observations of 1908, which are indicated by the letter Alpha and *Z*.

Mr. Wilkerson: Q. I want to ask you this question: You combine here different cross-sections. Now, there are certain fixed errors, are there not, where you have different cross-sections, which make it improper, if I may use that word, to combine the different cross-sections in figuring the increment?

A. I fail to see that. The increment is referred to the stage of lake, not to the stage at the gaging station, as I understand these observations. If this increment for each place has been figured with reference to a gage at a gaging station, then I have misunderstood the trend of the complainant's testimony entirely, and I would say that the deductions which have been drawn from it are absolutely incorrect. It is my understanding that the same reference gage is used, both in the Gorge measurements and in the Dry Dock measurements as presented in its table. If that is not the case, then these computations—

(Former answer of witness read as follows: "By the introduction of the observations of 1908, which are indicated by the letter Alpha and *Z*.")

The witness (continuing answer): On table 15 are presented the computations when introducing in addition to the observations of 1908 the observations of 1901, first using the corrected value adopted by the complainant. This is shown in the fourth column, and the increment is shown at the bottom of the page. Introducing these observations as adjusted or corrected by the complainant, the increment derived is about 2¾ per cent. greater than that presented on Complainant's Exhibit 1.

Mr. Wilkerson: Q. That is 24,436?

A. 24,436. It is intimated by the complainant's witness, in file 7 at page 82 of the record, continuous paging 630, that excluding the 1901 observations gave an increment favorable to the contentions of the defendant. If, however, the observations of 1901 be included with all the rest without correction, the resulting increment as shown on table 15, in the third, sixth and seventh columns is 27,861 cubic feet or nearly 17

per cent. greater than that given on the chart; and if the increment be increased, the effect of the diversion is decreased and the foregoing suggestion of the complainant's witness is therefore shown to be an error.

In this table 15, the first column indicates by letter the groups of observations as they have been used; column 2 indicates the average elevation of Lake Huron for each group of observations in question as given upon Williams' Exhibit 21.

Column 3 is three centers of gravity of the elevations. Column 4 is the value of the discharge with the corrected values for 1901 included. Column 5 gives the centers of gravity of these discharges in Column 4. Column 6 gives the observed discharges without correction. Column 7 gives the centers of gravity or means of these observed discharges, and the increment then is as stated and shown in the bottom line of the table, 27,861 cubic feet per second.

Mr. Adcock: Q. You say "corrected values for 1901." What do you mean by that, Mr. Williams?

A. In Complainant's Exhibit 21, at the foot of that table, referring to discharge measurements, Dry Dock Section St. Clair River, 1901, we find this note: "Discharge was decreased two-thirds of one per cent. for each tenth foot Lake St. Clair was below normal as expressed by equation; St. Clair equals 574.79 plus 0.66 (Harbor Beach minus 580)." This correction to these observations has been made in accordance with that equation and introduced to cover groups *V*, *W*. and *X* in the fourth column of table 15.

Q. Why were those corrections made, if you know?

A. On the assumption of the complainant that Lake St. Clair was in an abnormal position with reference to Lake Michigan. In other words, that it was too low, and therefore the discharge measured was higher than would have existed with St. Clair in its normal position.

Adjourned to Thursday, March 20, 1913, at 10 a. m.

March 20, 1913, 10 a. m.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Mr. Adcock: During the period of these gagings on the St. Clair, 1899, 1900, 1901 and 1902, what was the relation of the stages at St. Clair and Huron during those periods, as compared with the normal relation?

A. Your question is with reference to St. Clair and Huron?

Q. St. Clair and Huron.

A. The relations between Lakes St. Clair and Huron are shown on Table 17, in which the monthly mean elevations of Lakes Huron and St. Clair are shown in Columns 3 and 4 respectively for the months during which gagings were in progress on the St. Clair River, during the several years indicated in Column 1.

Column 5 shows the difference or fall from Huron to St. Clair. Column 6 gives the number of gagings each month, and the seventh column shows the weighted difference, or rather the difference multiplied by the number of gagings, the mean weighted difference being indicated in the eighth column.

And finally, in Columns 9 and 10 we have for each year the mean weighted elevations of Lakes Huron and St. Clair during the period of gaging, the weightings being dependent upon the number of gagings that were taken each month.

Q. Now will you explain just a little bit more in detail what you mean by weighting measurements or observations?

A. Yes. If during any month there had been one gaging, that difference of elevation, or the elevation for that month in the weighting would have been given a weight of one. If in the next month there were, say, 10 gagings, the elevations, the differences of elevations would have been given a weight of 10. And in the summation for those two, if they only were involved, the sum of the weights for the two months would be divided by 11, that is the sum of the number of gagings; thereby getting an average elevation or difference of elevation for the series of gagings. It happens that the number of gagings per month does not vary greatly. The highest number during 1899 is 16, which occurs in both July and November. The lowest number is seven, which occurs in September.

In 1900, the range was from 19 in December to seven, which occurred both in June and November. In 1901 there are but

two months, May having 16 and June 20. In 1902 there are two months, August having 18 and September 30; 1908 there are two months, November having 12 and December three. For the entire period covered by the gagings from 1899 to 1908, inclusive, the mean elevation of Lake Huron was 580.644, as derived by the previously described weighting, and that of St. Clair, corresponding, was 575.174, showing a fall from Lake Huron to Lake St. Clair of 5.47 as the weighted mean fall.

Q. That is feet?

A. 5.47 feet as the weighted mean fall during the periods of gagings involved.

Comparing this with Table 19 it is found in the second column, the third line from the bottom, the mean elevation of Lake Huron as given by the exhibits for the Lakes Michigan and Huron in Williams Exhibit 26, for the period from 1860 to 1908, inclusive, was 581.36. The mean elevation of Lake St. Clair as given in the said exhibits, and extended by the aid of the tables in the report of the International Waterways Commission, being Table 7, Water Levels of Lake St. Clair, page 90, or Exhibit 33 A-. The reason for reference to the report of the International Waterways Commission being that the gage elevations supplied by the United States Lake Survey for the St. Clair Flats begin with July, 1872, and that there are omissions in 1877, 1878, 1879, 1880, 1881, 1882 and 1883; also in 1902 and 1903. And in order to get a comparison it was necessary to have the record extended, for which purpose reference was made to the work of the International Waterways Commission. The mean elevation of Lake St. Clair so derived is 575.76, showing a difference or fall of 5.6 between the two lakes, as compared with 5.47 as derived on Table 17.

A similar comparison may be made by reference to Table 18 with the open season elevations, by open season understanding the period from April 1st to November 30th, inclusive. From 1860 to 1910 the mean elevation of Lake Huron was 581.52. The mean elevation of St. Clair, similarly derived to that testified regarding Table 19 was 575.98; giving a mean fall of 5.54 feet as compared with the 5.47 feet as shown on Table 17. Inasmuch as the records of Lake St. Clair for the period prior to 1872 have been derived by comparison with other gages, it has been thought wise to make a comparison between the elevations of Lake Huron and Lake Erie, both during the gaging periods, and during the period from 1860 to 1908, for the rea-

son that we have a continuous record of the elevations of Lake Erie, and that there is a relation between the elevation of Lake Erie and Lake St. Clair and Lake Huron, which is approximately constant for a large part of the time considered.

Table 16 presented in a similar manner to Table 17 differences of elevation between Lakes Huron and Erie during the months of discharge mentioned. The preparation and treatment of data in this table is similar to that in Table 17, the elevation of Lake Erie as taken from the tables of lake elevations in Williams Exhibit 26 being used in place of the elevations of Lake St. Clair, which, as before stated, were partially derived from Exhibit 26 and partially from the report of the International Waterways Commission, Exhibit 33.

At the bottom of Table 16, in the column headed "Mean Difference," second line from the bottom, we have the mean fall for the gaging periods, being the weighted mean fall from Lake Huron to Lake Erie given as 8.61 feet; the weighted mean elevation of Lake Erie being 572.033.

Referring now to Table 18 for the open season, the last page of the table, the third line from the bottom, we find as before the mean elevation of Lake Huron from 1860 to 1908 to have been 581.56, and in the next to the last column of the table, the third line from the bottom, the mean elevation of Erie for the same period to have been 572.85, showing a difference of 8.71 feet, as contrasted with the difference between these lakes in Table 16 of 8.61 feet. That is for the gaging period, using all the years included from 1899 to 1908. If the observations of 1901 be omitted, we have shown in the bottom line of Table 16, the mean weighted elevation of Lake Huron to have been 580.608, and the mean weighted elevation of Lake Erie to have been 572.115, giving a mean fall between the two lakes as shown in the column headed "Mean Difference" of 8.49 of a foot.

It therefore appears that between the mean elevations of these lakes for the open season and the weighted mean elevation as derived in Table 16 for the gaging periods, exclusive of 1901, there is a difference of over two-tenths of a foot, and if compared with the mean elevation of the lakes, as shown in Table 19, which embraces the full year, we have the mean elevation of Lake Huron given in the third line from the bottom of the last page of the table from 1860 to 1908 as 581.36, and the mean elevation of Lake Erie for the same period as 572.61, giving a difference of elevation of 8.75 feet, or nearly

.3 of a foot greater than that obtained by the use of the observations of the complainant, excluding 1901.

Table 19 is intended to be, so far as Columns 2, 4 and 6 are concerned, an accurate transcript of the mean elevations for the lakes in question as shown upon Williams Exhibit 26, furnished by the United States Lake Survey, with the additions from page 90 of the report of the International Waterways Commission necessary to complete the record of Lake St. Clair.

This change in fall has been due mainly, or we may say fully speaking relatively, to the fact that Huron was higher as an average from 1860 to 1908, than it was during the periods of gauging, by approximately .3 of a foot. And referring to the complainant's testimony as given in File 7, page 60, of the original record, or continuous paging 608, wherein it was stated that if the other lakes remained stationary, or more specifically if Lake St. Clair remained stationary and Lake Huron should raise .2 of a foot, the discharge would be increased 6,570 cubic feet per second, then it would follow, if Lake Huron had been .3 of a foot higher during these gaugings, the discharge would then have been increased by about 9,855 cubic feet per second.

If we were to take the actual differences of elevation between these lakes, the discharge of the St. Clair River would, according to our own computations, as will be explained later, have been something over 20,000 cubic feet per second greater, had the stages of the lakes been at their average position for the period from 1860 to 1908 instead of in the positions which they actually did occupy during the gauging period.

If the 1901 gaugings be included, the average difference of elevation between Huron and Erie, as already pointed out, during the period of gaugings as shown in Table 16, was 8.61 feet, or 50 per cent. nearer to the normal difference of elevation as established from the open season records of the 49 years from 1860 to 1908 than is the fall derived from the observations without 1901, which seems to be that used in the derivation of Complainant's Exhibit 1 of the increment of the St. Clair River. And it has therefore been concluded by me that the value of the increment derived from all these observations being based solely upon a variation of elevation of Lake Michigan-Huron is a more nearly correct value to be applied than the one adopted by the complainant; that value being 27,861 cubic feet per second.

It may be remarked here that the complainant's witness,

Mr. Wheeler, File 4, page 45 or page 141 of the continuously paged record, gives the St. Clair increment from his own computations as 25,300 cubic feet per second.

Q. Upon what theory, as shown by the testimony adduced by complainant, are the increments for the St. Clair River derived, and what errors of assumption appear to you in that derivation?

A. The increments derived by the complainant for the St. Clair River are based on the assumption that an increment can be derived for that stream without reference to Lake St. Clair, and that the observations considered are sufficient for that purpose. While it is probable that if for a sufficient period of years gaugings were made every day so as to cover all possible positions of both Lake Huron and Lake St. Clair, and no changes occurred in the channels connecting the two meanwhile, the assumption of the complainant might lead to accurate results. A comparison of the conditions existing between the two lakes during the gauging periods as shown in Table 17 with the average conditions existing as shown in Tables 18 or 19, being Williams' Exhibit 34, shows the incorrectness of the assumption with the limited number of observations thus far made, for while the average fall between these lakes for the periods of gauging as shown on Table 17 was 5.47 feet, the average fall for the full year for the period from 1860 to 1908, as shown on Table 19, third line from the bottom, was 5.6 feet. Since the velocity in an open channel is very nearly proportional to the square root of the fall, other things remaining the same, the increased fall for the latter period would theoretically increase the velocity by the square root of 5.60 divided by the square root of 5.47, or by about 1.2 per cent.

The discharge would be further influenced by the elevation of Lake Huron. During the gaugings, the mean elevation of Lake Huron as shown in Williams' Exhibit 24, and compiled in table 19 of Exhibit 34, from 1860 to 1908 was 581.36. If we accept for the purpose of this discussion the contention of the complainant that there has been no change in the conditions of outflow of the St. Clair River, it appears that the depth of water at the head of the river in which the discharge measurements were made, was .65 of a foot less during the measurements than during the average of the 49 years under consideration.

Q. Look at the printed book which I now hand you and state what that is?

A. This is Appendix III to the report of the Chief of Engineers for 1900, of which pages 5379 and 5380 show in the seventh column the area of the Dry Dock Section used in gauging the St. Clair River as 60,935 square feet. The width of the section is stated on page 5364 to have been a little over 2100 feet, and the depth is shown on Plate 12 of the same report as approximately 35 feet, over something more than half of the section.

Mr. Adcock: We offer for identification pages 5362 to 5401 inclusive of the Report above described for 1900. And it is stipulated between counsel that the book itself need not be marked, but that it may be considered as identified so as to avoid the necessity of encumbering the record with so large a publication.

Mr. Wilkerson: Either such portions as are indicated or such other portions of the report as we may wish to direct attention to if occasion requires.

The Witness: If the depth were increased .65 of a foot, there would be an added area of at least .65 times 2100 or 1365 square feet, or about 2 1/4 per cent. of the total cross section. This added depth increases the hydraulic mean depth so-called from about 28 to about 28.7 and increases the discharge approximately in the ratio of the square roots of these mean depths, or as the square root of 28.7 divided by the square root of 28, which gives an increase of about 1 per cent.

The combined influence of increased slope, increased area and increased depth are then 1.012 multiplied by 1.0225 multiplied by 1.01 equals 1.045 and the average discharge of the St. Clair River, if there have been no changes in the channel affecting the discharge must have been very nearly 4 1/2 per cent. above the gaugings of 1899 to 1902 as an average of the period of 1860 to 1908. And if the discharge were increased, the increment in all probability would have been increased to some extent. The increment deduced by the complainant would indicate that the quantity of flow under average conditions for the open season, when the difference in stage of Huron is .92 of a foot.

By tables seventeen and eighteen, higher than during the average of the gaugings, must have been fully 10 per cent. greater than that observed.

In other words, during the average period from 1860 to 1908, the discharge through the St. Clair River must have been something over 20,000 cubic feet a second greater than

it was during the periods in 1899, 1900, 1901, 1902 and 1908, when the complainant made its gaugings.

However, as it appears to me that the normal relations between Lakes Huron, Erie and St. Clair as established by the relative positions by the annual elevations of those lakes for the period from 1860 to 1908, inclusive, did not exist during the period covered by the observations, I think it necessary to derive an increment in such a manner that it can be applied with the normal relation to get a more accurate value of the discharge, and consequently of the effects of diversions. To do this, the influences of Lakes St. Clair and Huron must be separated, which may be done by determining increments for the effect of each when each lake was at a constant elevation, and the other changing. If the observations from 1899 to 1908, inclusive, be arranged in groups with Lake St. Clair at a uniform elevation for each group, which arrangement has been made in table 22 of Exhibit 34, there are fifteen such groups of from four to thirty-one observations, and an increment may be determined from each group, according to the methods already discussed in the examination of the increments derived by the complainant in connection with testimony relative to Tables 1 to 4 of Exhibit 34, and these increments with the essential figures of the computation, therefore, are presented on Table 22 of Exhibit 34.

In this Table 22, column 1 gives the number of observations in each group. Column 2 gives the elevation of Lake St. Clair for the observations in that group. Column 3 gives the elevation of the center of gravity, or the center of gravity of the elevations of Lake Huron for each group; and column 4 gives the center of gravity of the discharges for each group. Column 5 gives the center of gravity of the elevations of Lake Huron for the upper portion of the group; column 6, the center of gravity of the discharge for the upper portion of the group; column 7 the center of gravity of the elevations of Lake Huron for the lower portion of the group; and column 8 the center of gravity of the discharge for the lower portion of the group. Whence the equation in column 9 is derived, and the increment then is the coefficient of Y in said equation, and is shown in column 10. The arithmetic mean of these increments is shown at the bottom of column 10.

There are shown in the Table 15 such groups, of from four to thirty-one observations, and the increments determined from the several groups range from eighteen thousand, six hundred cubic feet per second from a group of

six observations, to forty-four thousand, three hundred and twenty-five cubic feet per second, from a group of fourteen observations. The mean of the fifteen determinations being 34,385 cubic feet per second, as the arithmetic mean, or when weighted by the number of observations in each group as shown in Table 24, the left hand portion, the weighted mean is 36,187 cubic feet per second as the effect of a rise of one foot on Lake Huron on the discharge of the St. Clair River, when Lake St. Clair does not change.

To introduce the effect of Lake St. Clair, we make a similar arrangement of the observations which is shown in Table 23 of Exhibit 34, arranging the observations in groups, with Lake Huron at a uniform elevation for each group.

In column 1 of this table is shown the number of observations in each group; column 2 the elevation of Lake Huron for that group, and columns 3-4, 5-6, 7-8, giving the three centers of gravity of the elevation of Lake St. Clair, and the discharge. Column 9 gives the derived equation and column 10 the increment and the mean of the increment is stated at the bottom of the page.

There are twenty-one groups of from three to seven observations, giving increments ranging from minus thirty-one thousand to plus 12,800, with a mean of 14,072 cubic feet per second, unweighted, or as shown in Table 24, Exhibit 34, a mean of minus 12,995 cubic feet per second, when weighted according to the number of observations in each group, as the effect upon the discharge of the St. Clair River of one foot rise of Lake St. Clair when Lake Huron remains stationary. Or, in other words, when Lake St. Clair rises one foot if there were no other change in the river, the discharge would be decreased 12,995 cubic feet per second, and if Lake Huron raised one foot and there were no other change, the discharge would be increased 36,187 cubic feet per second.

To explain the meaning of the term "weighted", as used in this answer, I would say that we conceive that if a group has three observations, and another group has six observations, that the second group is entitled to twice the reliability of the first group on the theory that all observations are of equal accuracy, and that all are somewhat in error. Therefore, in reducing these observations, we have multiplied the result of each group by the number of observations in it, added those sums, and divide by the total number of observations to get a weighted mean; thereby giving ourselves the benefit of a large number of observations, in which each is

treated as of the same value over the average of the same number of observations, where they would not be treated of the same value if we took the direct or arithmetic mean of the last columns of Tables 22 and 23.

In connection with this method of deriving an increment for the St. Clair River, I would call attention to the testimony of complainant's witness Shenehon, it appearing in file 7, at page 102-103 of the record, or on pages 650 and 651 of the continuous paging of the record, in which the propriety and correctness of an increment derived in this manner was submitted, when, in answer to the question: "Q An increment obtained in that way would be likely to be at least approximately correct," the witness answered "Yes."

Complainant's witness Shenehon, in file 7, page 60 of the record, or at page 608 of the continuous page record, states the back water effect of Lake St. Clair to be about two-thirds of one per cent. of the discharge for one-tenth foot rise, which when applied to the mean of the gaugings of 1889 to 1908, which is given in Table 15, being part of Exhibit 34, in the last column in the middle, as 196,908 cubic feet per second, gives minus 13,130 cubic feet per second as the increment for one foot rise of Lake St. Clair.

It is further stated by the same witness in file 7 at page 58, or page 606 of the continuously paged record, that the normal relation between changes in elevation in Lakes Huron and St. Clair is that 66 per cent. of the change of the former appears in the latter.

I might at this point call attention to the fact that the increment derived from the complainant's testimony above cited, on page 606, of 13,130 cubic feet per second coincides very closely with the value derived in Table 23 of Exhibit 34, as weighted in Table 24 of the same exhibit, which is 12,995 cubic feet per second.

It is also stated by the same witness in file 6, at page 38, or one page 496 of the continuously paged record, that the effect on the elevation of Lake St. Clair is eighty per cent. of the average of the changes in elevation of Huron and Erie, and Lake Erie is stated by the same witness, in file 7, page 43, being page 591 of the continuously paged record, that the elevation of Lake Erie varies by 70 per cent. of the change of the elevation of Lake Huron. Then the mean change of the two lakes, based upon the last two citations, is 1.00 plus .70, divided by 2, equals .85 of the Huron change; and the Lake St. Clair change then is .80 times .85, equals 68 per cent. of

the Huron change. In other words, the testimony of the complainant's witness leads us to substantially the same relation between a change of elevation of Lake Huron and a change of elevation of Lake St. Clair, whether it be derived from the direct statement in file 7 at page 58, or by a combination of the two statements of file 6, page 38, and file 7, page 43.

It then follows that under normal relations, if Lake Huron rose one foot and increased the flow 36,187 cubic feet per second, Lake St. Clair would rise .66 to .68, or say 66 2/3 per cent of a foot, and reduces the discharge by 66 2/3 per cent. of 12,995, or by 8,664 cubic feet per second, leaving the net increment for one foot of change on Lake Huron, under normal conditions, as 36,187 minus 8,664, or 27,523 cubic feet per second, or within 1 1/2 per cent of the value previously obtained by using the 1901 observations with the rest. The value, 27,523, is about 11 per cent. greater than the value mathematically determined from the observations of 1899, 1900, 1902 to 1908 by the previous computation, when the relative elevations of the two lakes were neglected; and over 15 per cent. greater than the value given on Complainant's Exhibit 1.

Recess to 1:45 P. M.

After recess—1:45 P. M.

GARDNER S. WILLIAMS resumed the stand and testified further, as follows:

The relations between the elevations of Huron, St. Clair and Erie, to which the complainant's witness testified in the citations to which reference has just been made, were based apparently upon average conditions from 1860 to 1908; but these conditions changed materially about 1890, and while as shown by Table 21 of Exhibit 34, the changes of annual elevation of St. Clair are about 68 per cent. of those of Huron for the period from 1860 to 1889 inclusive, the changes of elevation of St. Clair for the period from 1891 to 1910, inclusive, are about 89 per cent. of those of Huron.

In Table 21 of Exhibit 34, in the first column, are indicated the periods 1860 to 1889, and 1891 to 1910. In column 2 are given the years; and in column 3 the elevation of Lake Huron for each year enumerated in column 2.

In column 5 is given the elevation of St. Clair for the same years as enumerated in column 2. Column 4 gives the centers of gravity of the two groups, and the whole of the elevations of Lake Huron in column 3 for each of the periods; and column 6 gives the similar centers of gravity for the elevations of Lake St. Clair.

At the foot of the table, under 1860, it is shown by a subtraction of the lower center of gravity, for the period 1860 to 1889, from the upper center of gravity of the same time, that the mean elevation of Lake Huron changed 1.131 feet. During the same time, as shown by the subtraction of the lower center of gravity of the elevation of Lake St. Clair from the upper center of gravity for the same period, the mean elevation of Lake St. Clair changed .767. The ratio of the change of elevation of Lake St. Clair to the change of elevation of Lake Huron is therefore .767, divided by 1.131, or 67.8 per cent., which coincides with the relation testified to by the complainant's witness before cited.

For the period from 1891 to 1910, similarly, subtracting the lower center of gravity of the elevation of Lake Huron from the upper center of gravity for this period, the difference of mean elevation is 0.577. Similarly, for Lake St. Clair, subtracting the lower center of gravity from the upper center of gravity of the elevations as given in column 6, the difference of mean elevations is found to be 0.516.

The ratio of the change of Lake St. Clair to the change of Lake Huron for the period from 1891 to 1910 is therefore found to be 0.516 divided by 0.577, or 89.4%.

If instead of using the relation between St. Clair and Huron, as testified to by the complainant's witness, we use the relation which is derived for the period since the apparent change of conditions in 1891, the increment for the St. Clair River as derived from the computations in Tables 22, 23 and 24 of Exhibit 34 becomes 36,187 minus .89 times 12,995, equals 24,620 cubic feet per second.

In the reduction of the observations for discharge so far considered, it has been assumed that the discharge observed is that due to the elevation of the Lake surfaces existing during the actual gaging. In many observations this was not simultaneously observed, and has been determined, as stated by the complainant's witness in file 6, at page 16, being page 474 of the continuously paged record, by a series of comparisons between a gage at or near the gaging station, and the controlling lake gage. The gage elevations set down as thus

corresponding to the discharge measurements in Exhibit 21 can then be regarded as representing only approximately the conditions producing the discharge, which will also be influenced by the situation of the lake surface during many antecedent hours.

In other words, it is my conception that the discharge of the river cannot instantly respond to a change of lake elevation in its entirety; that while the change of lake elevation increases the discharge of the river immediately, it does not get its full increase, the discharge does not get its full increase due to that change of elevation or that rise of elevation until some time afterwards. The values determined in the preceding investigation and those presented by the complainant, are therefore all subject to an error which has yet been nowhere considered. On account of the inertia of the water, the discharge does not respond instantly to a change of lake elevation, nor is the full effect of a change felt until its influence has traveled through the entire length of the river in question, and caused an acceleration or a retardation of every particle in it, and the rise or fall of stage throughout its full length.

In Appendix EEE of the Report of the Chief of Engineers for 1904, at page 4093 there appears the following statement: "In 6.4 days, therefore, after a rise occurs in Lake Huron, 9/10ths of the resulting rise will have taken place in Lake St. Clair." In other words, it takes, according to this statement, practically a week for the effect of a rise of Lake Huron to travel through the St. Clair river, and the full and final effect of that rise cannot therefore be said to have taken place in that river until after the expiration of this time.

As the change in discharge is an effect of the change in stage, it cannot precede it on any supposition; and on account of the tremendous mass of matter involved, a river of water nearly half a mile wide and forty miles long, weighing about three hundred million tons, the effect cannot be simultaneous or even approximately contemporaneous with the cause, so that it necessarily follows that the variations recorded in Lake stage from one observation to another will ordinarily be greater than the true variation corresponding to the change of discharge.

In other words, changes of discharge obtained by observations on fluctuating reservoirs will under all ordinary circumstances, be too small in relation to the changes of surface elevations. Incidentally it follows that the nearer the gaging

station is to the outlet of the lake, the more closely will the effects there coincide in time with the causes in the lake producing them. To fully correct this error from the observations in hand is impossible.

Mr. Adcock: What do you mean by "The observations in hand?"

A. The observations which have been furnished by the complainant relating to these discharges. And it would require many times the number we now have to eliminate it. But the observations in our possession may be grouped chronologically and periods selected when for a considerable time the range of variation of the lake surfaces was small, and from these groups an increment may be obtained by a more precise method than any yet used, for the conditions existing during the period covered by the observations.

In other words, instead of using a single simultaneous elevation of the lakes at the time of gaging, it is proposed to use the mean of a series of elevations, consecutively observed, and the mean of the gagings during the period over which those elevations extend, to get a more correct relation between change of lake stage and change of discharge.

Examining the data on the St. Clair from 1899 to 1902, we find eleven periods ranging in length from four to ten days, and including from four to eleven discharge measurements, during which the variations of the lake surfaces and the times of the discharge observations were such as to permit the computation of a mean elevation and a corresponding mean discharge, that, in our judgment, should be reasonably representative. These observations, their groupings, are presented in Table 28 of Exhibit 34, comprising three sheets.

These observations were grouped first, by periods when, according to the records furnished by the United States Lake Survey as presented in Williams' Exhibit 28, Lake St. Clair was at a uniform elevation during the full period of each group. They were also selected during such periods as the elevation of Lake Huron appeared to be either approximately constant or as the variations balanced and brought the initial and final position of the lake to substantially the same level.

In the first column of Table 28 is found the number of the group. In the second column is given the date of the observation, and it will be noticed that in each of these groups the elevation of Lake St. Clair has been started one day ahead of the elevation of Lake Huron, and has been stopped one day prior to the cessation of the record of the elevation of Lake Huron.

In the third column is presented the elevation of Lake Huron as indicated on Exhibit 21, and in the fourth column the elevation of Lake St. Clair as presented upon the same exhibit. In the fifth column is presented the mean daily elevation of Lake Huron as shown in Exhibit 28, being the mean daily elevation of Lake Huron at Harbor Beach. In the sixth column is presented the mean daily elevation of Lake St. Clair as shown in Exhibit 28, it being the mean daily elevation at the St. Clair Flats. In the seventh column is presented the observed discharge, which is taken directly from the last column of Exhibit 21.

In the eighth column is indicated the weight given to each discharge, said weight being determined by the length of time which the discharge is assumed to represent, it being assumed to extend or cover one-half the period each way to the next observation of discharge, except in the case of the first observation, when it is assumed to begin at the beginning of the day on which it is taken, and in the case of the last, when it is assumed to terminate at the end of the day on which it is taken.

In the last column of the table are given the products of the weight by the observed discharge, and in the footing of each group the averaged weighted discharge for the period, while the fifth column gives the average elevation of Lake Huron at Harbor Beach; and the sixth column the average elevation of Lake St. Clair at St. Clair Flats.

The data of this table as presented is sufficient to enable the accuracy of the transcription to be checked by comparison with Exhibits 21 and 28.

In this particular table, the discharges have been weighted, as just stated, by the time interval which they are supposed to represent; it being assumed that the discharges represent consecutively the changes of condition in the river from time to time. If a discharge had been taken every day, and only one, there would be no occasion to weight them. We should then simply take the mean of the discharges, but as on some occasions a day elapsed between the measurement of discharges, it becomes necessary to give those discharges which were taken before and after the interval, an additional weight in order to cover the interval in order that the time covered by the discharges may correspond with the time covered by the record of lake elevations.

Mr. Wilkerson: If two observations were taken on three days, you would give each one a weight of one and a half?

A. A weight of one and a half, that is the proposition.

We then have eleven observations showing a mean position of the surface of Lake Huron, mean position of the surface of Lake St. Clair moved twenty-four hours ahead, and the mean discharge observed for this time.

Q. Why do you take twenty-four hour periods?

A. Because we had to cover the full period that the lake was in the position. We could not select periods of elevation of the lake. We are taking a continuous period from the beginning to the end, in order that we may get at the mean position of the lake during that time.

Q. You say you take St. Clair twenty-four hours after Huron?

A. I take it twenty-four hours ahead. I assume the effect of Lake St. Clair, being so much further away from the gaging station, will not bring its full effect to bear as rapidly or as soon as Lake Huron.

Q. Why do you assume twenty-four hours?

A. I might have assumed some other period.

Q. Might have assumed six or eight hours?

A. I would have assumed more rather than less, or six days and a quarter to be precise. In these cases it would have very little bearing, as according to the record Lake St. Clair was at a constant position all the time. We find for several weeks in this record that Lake St. Clair did not vary one-hundreth of a foot.

As there are not a sufficient number of observations to enable us to determine a series of equations for periods of approximately uniform stage, when Lake Huron would be quiescent and Lake St. Clair moving, it is not possible to derive a new increment for the back water effect of Lake St. Clair by a method in harmony with the one which has just been outlined. We would need a great many more observations, and it is doubtful if the process could ever satisfactorily be applied, by reason of the fact that the surface of Lake Huron will not remain stationary for more than a very limited length of time. In view of the fact, however, that the back water effect as derived in my previous computations substantially coincides with that which has been testified to by the complainant, in the further production of an increment from the groups of observations in Table 28 of Exhibit 34, it has been assumed that the back water effect of Lake St. Clair is minus 13,000 cubic feet per second, upon the discharge of the St. Clair River.

In other words, it has been assumed, on the basis of the tes-

timony of the complainant, and the results of my own computations, as set forth in Tables 22, 23 and 24 of Exhibit 34, that the effect of one foot rise of Lake St. Clair upon the discharge of the St. Clair River, is to reduce that discharge 13,000 cubic feet per second.

Accepting for the purpose of argument the statement of the complainant's witness that a rise of one foot in Lake Huron is normally accompanied by a rise of two-thirds of a foot in Lake St. Clair, we proceed to the derivation of an increment by correcting the positions of Lake St. Clair to its normal position, with reference to Lake Huron, in accordance with the above mentioned ratio.

Table 19 of Exhibit 34, presents the first step in this reduction. The mean elevation of Lake Huron for the open season from 1890 to 1910, as has been shown on Table 18, was 580.70; and the mean elevation of Lake St. Clair from 1890 to 1910 was, as shown on the same table, 575.36. And it is assumed that for every change of Lake Huron above or below 580.70, Lake St. Clair should change two-thirds as much from 575.36. We are therefore able, by taking the changes of Lake Huron to compute a normal position for Lake St. Clair.

In Table 29, the first column shows the number of gagings included in the groups. The second column gives number of the groups; the third the days in the groups, and the fourth the period covered by each group, the fifth the average elevation of Lake Huron, all being as indicated in the preceding Table 28. In the sixth column of the table headed "Change from mean," is shown the change of Lake Huron from the mean elevation of 580.70.

In the seventh column is shown the mean elevation of Lake St. Clair as taken from Table 28; and in the last column again marked "Change from mean," is shown the change of Lake St. Clair from the mean position of 575.36.

We now come to Table 30 of Exhibit 34. Column 1 gives the number of the group. Column 2 gives the observed change from mean of Lake Huron. Column 3 gives the observed change from mean of Lake St. Clair, those three columns being taken directly from Table 29. Column 4 gives the normal change of Lake St. Clair; that is, that change corresponding to 66⅔ per cent. of the change of Huron as indicated in Table 2. And Column 5 gives the difference between the normal change of Lake St. Clair and the observed change of Lake St. Clair, with its proper sign, as to whether the normal would have been above or below the observed change. A rise of one

foot in Lake St. Clair being assumed to cause a decrease of discharge of the river of 13,000 cubic feet per second, it is then possible, by multiplying the differences in Column 5 by 13,000 to get the results in Column 6, which are the corrections to the discharge due to the abnormal position of Lake St. Clair.

Column 7 is the observed discharge of the St. Clair River for the period in question, as taken from Table 28. And Column 8 gives the observed discharge plus the correction for the abnormal position of Lake St. Clair in Column 6, and represents, on the foregoing theory, the discharge of the river which would have existed had Lake St. Clair been in its normal relation to Lake Huron, as shown by its average position from 1890 to 1910; assuming, according to the testimony of the complainant, that the change in Lake St. Clair is two-thirds of the change in Lake Huron, and that the effect of one foot rise in Lake St. Clair is to decrease the discharge of the St. Clair River 13,000 cubic feet per second.

Table 31 presents the next step in the computation of the increment. Column 1 again represents the number of the group; Column 2 the mean daily observed position of Lake St. Clair taken from Table 28. Column 3 the corrected discharge taken from Column 8 of Table 30. Column 4, a multiplier being the number of days that are included in each period of gauging, in order that the several values of the several periods may be weighted according to the length of time. Column 5, the corrected discharge multiplied by the factor in Column 4. Column 6, the mean daily elevation of Lake Huron taken directly from Table 28. Column 7, the product of multiplying the mean daily elevation of Lake Huron by the number of days over which the observations extend. Column 8, the centers of gravity of the weighted discharges, or the weighted products of discharge, when divided by the sum of the multipliers involved in each portion of the series, and Column 9, similarly, the weighted centers of gravity of the position of Lake Huron.

Mr. Wilkerson: Q. I think you have explained already, Mr. Williams, but I wish you would tell us again why in Group 1. Column 1, Group 1, in the fourth column, where you have a multiplier of ten, why you put ten there.

A. Turn back to Table 29, and you will find that Group 1 covers a period of ten days, and we have weighted according to time.

We then find from Columns 8 and 9, subtracting the lower center of gravity of discharge from the upper, that a change of 15,820 cubic feet per second, corresponded to a change of

elevation, subtracting the lower center of gravity from the upper center of gravity in Column 9 of 0.507 feet. Whence the deduced increment of the St. Clair River is 31,203 cubic feet per second.

In Table 32 we start again with the data of Table 29, Exhibit 34, this time assuming that the change of St. Clair corresponding to a change of Huron has been such as is indicated by a comparison of the annual changes of the lakes from 1890 to 1910; or that a change of one foot in Lake Huron is accompanied by a change of 89 per cent. of one foot in Lake St. Clair, and that the effect of a rise of one foot in Lake St. Clair is as before to reduce the discharge of the St. Clair River 13,000 cubic feet.

Table 32 then corresponds to Table 30, in the previous computation. And it is perhaps interesting to note that in this instance Group 1 represents normal relations, there being no correction required to the position of Lake St. Clair.

Column 1, as in the previous table, gives the number of the group. Column 2, the change of the elevation of Huron from the mean. Column, 3, the observed change of elevation of Lake St. Clair from the mean. Column 4, the normal change of Lake St. Clair from the mean, as determined by multiplying the change of Lake Huron by .89.

Column 5, the difference between the normal position of Lake St. Clair, and the observed position. Column 6, the correction due to the change of St. Clair from its normal position, being the product of 13,000 by the difference indicated in Column 5. Column 7, the observed discharge, corresponding to Column 7 in Table 30, and taken directly from Table 28. And Column 8, the corrected discharge or the discharge which it is assumed would have existed, had Lake St. Clair been in its normal relation to Lake Huron, as determined by its mean relation from 1890 to 1910, and by the annual changes of elevation of the two lakes throughout the same period.

Table 33 then corresponds to Table 31, in which column 1 gives the numbers of the groups; column 2, the mean daily elevation of Lake St. Clair, Column 3, the corrected discharge as taken from Column 8 of Table 32. Column 4, the multiplier, being the number of days over which each group of observations extends. Column 5, the product of the multiplier by the discharge. Column 6, the mean daily elevation of Lake Huron. Column 7, the product of the multiplier by the elevation of Lake Huron, Column 8 the centers of gravity of the weighted

discharges and Column 9 the centers of gravity of the weighted elevations.

Subtracting the lower center of gravity of Column 8 from the upper, we find that the discharge was increased 14,638 cubic feet per second, for the change of elevation of Lake Huron indicated by the difference between the lower center of gravity and the upper center of gravity in Column 9, or 0.507 foot, which represents an increment of 28,872 cubic feet per second.

I now examine the gaugings of the St. Clair River made at Dry Dock Section, Section Gorge, during the years 1908, 1909 and 1910, as presented in Exhibits 22 and 23. These gaugings embrace 58 measurements at the Dry Dock Section, covering a range of Lake Huron elevation from 580.54 to 579.45; and 209 measurements at the Gorge Section, covering a range from 580.75 to 579.45, all of which have been combined.

In view of the testimony of complainant's witness Shenehon, file 6, page 44, or page 502 of the continuously paged letters, in which in answer to "Q. What do you say as to the precision of River Gauging done by the Lake Survey? A. I consider a discharge measurement, or rather a series of them, to have a precision of one per cent.," and in view of the further testimony of the same witness in file 6, page 49, or page 507 of the continuously paged record, in answer to the question: "Q. What do you think to be the precision of your observations as to sounding? A. That is well within one per cent. in all cases," it does not seem to me that it was necessary to separate the discharges at the Dry Dock Section, as taken in 1908, 1909 and 1910, from those at the Gorge Section taken during the same years by the same parties, who had already had the benefit of the previous experience to which the complainant's witness testified.

These observations have been examined in a manner similar to those of 1899, 1900, 1901 and 1902. The determination for the case of Lake St. Clair at a constant elevation during this latter period is given in Table 25, in which there are 47 groups ranging in number from two to seventeen observations, in which the elevation of Lake St. Clair was the same in each.

I may remark, during these later observations, Lake St. Clair does not appear to have been nearly so accommodating as it was during the previous period, where for weeks it remained conveniently at one elevation, but during this period it seems to change almost daily.

This Table 25 corresponds with Table 22 already described.

Mr. Adcock: What does that indicate?

A. It might indicate two things; one that he had a different—

Q. That is your last statement?

A. One, that we had a different kind of water, something approaching to molasses, or syrup during the observations of 1899 and 1910; and that during the later periods we had a more volatile liquid approaching perhaps to the ordinarily recognized water, or possibly to alcohol. Or, it may indicate that during the earlier period, the gauge reader slept at his watch at times, and failed to record the elevation that actually existed, and later, some days later, filled his note book with a record connected from his mind, in which he carried on the same elevation that he had last observed, until he happened to go to the gauge and take another one.

I think this is a fair commentary upon the general accuracy of the readings that have been introduced in this case, during particularly the earlier periods covered by the testimony, and it shows one of the great sources of error, which no refinements of mathematics or assumptions of the investigator can possibly eliminate.

Columns 3-4, 5-6 and 7-8, give the centers of gravity of the elevations of Huron and the discharges for the respective periods.

Column 9 gives the deduced equation, and Column 10 the increment, whose arithmetic mean would seem to be 34,510. When these values of the increment are weighted in proportion to the number of observations included in each group, as shown in the first half of Table 27, of Exhibit 34, in a manner similar to that described with reference to Table 24 of the same exhibit, the increment of the St. Clair River due to a change of one foot in Lake Huron, as indicated by the combined gaugings at the Dry Dock and Gorge Section of the observations of 1908 to 1910, inclusive, is found to be 35,797 cubic feet per second, or within 400 cubic feet per second of the value similarly deduced from the observations from 1899 to 1902 by a similar process of investigation.

Table 26 presents the increments due to changes of Lake St. Clair, when Lake Huron was at a constant elevation, or at the same elevation, and corresponds to Table 23 of Exhibit 34 previously described, and embraced forty groups of from two to eleven observations; the number of observations in each group being indicated in Column 1, Table 26.

Column 2 gives the elevation of Lake Huron. Columns 3-4, 5-6, 7-8, give the respective centers of gravity for the elevation of Lake St. Clair and for the discharge.

Column 9 gives the derived equation and Column 10 presents the individual increments, whose arithmetical mean is minus 12,230 cubic feet. And when these increments are weighted by the number of observations in each group as presented in the right-hand half of Table 27 of Exhibit 34, they being weighted in proportion to the number of observations in each group, the weighted mean effect of the rise of one foot in Lake St. Clair upon the discharge of the St. Clair River, other things remaining unchanged, is found to be eleven thousand eight hundred and seventeen cubic feet per second, or about 900 cubic feet per second less than that in the previous computation.

If we now apply to these computations the ratios stated by complainant's witness of the rise in Lake St. Clair to the rise in Huron, namely, that when Lake Huron rises one foot, Lake St. Clair rises two-thirds of a foot, we have as the net increment of the St. Clair River, 35,797 minus two-thirds times 11,817, equals 27,919 cubic feet per second.

If we apply the ratio for changes of St. Clair to changes of Lake Huron, as derived from the annual changes or from the mean annual elevations from 1890 to 1910, we have as the net increment 35,797 minus .89 times eleven thousand eight hundred and seventeen (11,817), equals 25,280 cubic feet per second.

In Table 34 of Exhibit 34, I have examined the observations of 1908 to 1910, at the Dry Dock and Gorge Sections, of the St. Clair River, by a method similar to that presented with reference to the earlier observations in Table 28, in which case it has been possible to select seven groups of observations when for considerable periods the surfaces of Lake St. Clair and Lake Huron showed moderate divergence from their mean position during the periods selected.

These observations are arranged in Table 34 in a manner entirely similar to that adopted in Table 28, with reference to the preceding observations.

Column 1 gives the number of the group, the numbering having been continued from that of the previous table.

Column 2 gives the dates of the observations indicated. Column 3 gives the mean daily elevation of Lake Huron, Column 4 gives the mean daily elevation of Lake St. Clair. The observed elevations of Lake Huron and Lake St. Clair have been omitted from this table.

Column 5 gives the dates of the discharge measurements, and it appears that in this case several measurements were made in a single day, frequently as many as five and in one

case at least six. Column 6 gives the observed discharge of the several measurements, and the mean discharge for the period. The mean elevations of Lakes Huron and St. Clair are given in Columns 3 and 4, in addition to the daily elevations.

The discharges observed as presented in the sixth column have been weighted by the time interval which they represent, which in this table is usually fractional, on account of there generally having been more than one observation in a day, and the last column of the table gives the weighted discharge, said discharge being weighted in proportion to the time covered between it, and the intermediate point between it and the next. The last column also gives the mean weighted discharge for the groups.

On Table 35 of Exhibit 34 is shown the information corresponding to that previously presented in Table 29 of the same exhibit relative to the first service of gagings.

In the first column is presented the number of the gagings in each group, which is seen to range from ten to fifty-five.

The second column gives the number of the group, and the third the number of days in the group, which is seen to range from five to twenty. The fourth column gives the dates covered by the period. Column 5 gives the observed mean daily elevation of Lake Huron during the period of gagings, and Column 6 the change from the mean daily elevation of Huron, the mean elevation of Lake Huron from 1890 to 1910 for the open season, of 580.70, being taken as the mean position, and for Lake St. Clair the mean elevation during the open season, of 575.36, for the period from 1890 to 1910, being taken as the mean position.

The seventh column gives the mean daily elevation of Lake St. Clair, and the eighth column the change in the elevation of Lake St. Clair from its mean position of 575.36.

Table 26, which corresponds to Table 30 previously described, gives first, in the first column the number of the group; in the second column the observed change of Lake Huron from the mean as derived from Table 35. Column 3, the observed change of Lake St. Clair from the mean as derived from the same table, Table 35. Column 4, the assumed normal change of Lake St. Clair from its mean position, being the change of Huron multiplied by 66 2/3 per cent. in accordance with the testimony of the complainant's witness. Column 5, the difference between the observed change from mean of Lake St. Clair and the computed normal change from the mean position.

Column 6 then gives the correction due to the position of St. Clair, being the difference in Column 5 multiplied by the previously computed increment of the effect of Lake St. Clair as shown in Table 27, which is there given as minus 11,817; but has been taken for our computations as minus 12,000 cubic feet per second.

It is unnecessary, I assume, to call attention to the fact that any increase in the back water effect of Lake St. Clair in this computation is not to the advantage of the defendant; or, perhaps, is not to the prejudice of the complainant.

Column 7 gives the observed discharge as obtained from Table 24 and Column 8 the discharge corrected for Lake St. Clair in its assumed normal position in reference to Lake Huron by the addition, with its proper sign, of the correction in Column 6 to the observed discharge in Column 7.

Table 37 corresponds to Table 31. The first column gives the number of the group. The second column the mean daily elevation of Lake St. Clair; the third, the corrected discharge; the fourth, the multiplier for weighted observation, being the number of days in each period; Column 5, the product of the discharge by the number of days; the sixth column, the mean daily elevation of Lake Huron; Column 7, the product of the mean daily elevation of Lake Huron by the number of days; Column 8, the weighted centers of gravity of the discharge; Column 9, the weighted centers of gravity of the elevations of Lake Huron. When it appears, by subtracting the lower center of gravity of the discharge from the upper center of gravity as shown in Column 8, there is a difference of 11,389 cubic feet per second, which occurs during the range indicated by the difference between the upper center of gravity in Column 9 and the lower center of gravity in the same column, or .268 of a foot; and gives, therefore, an increment of 30,948, or less than five hundred cubic feet per second difference from the increment obtained in Table 31 from the observations of 1899 to 1902, by a similar process of examination.

Table 38 corresponds to Table 32, in that, instead of using the ratio for change of Lake St. Clair with reference to Lake Huron, testified to by the complainant, there has been used the ratio determined by the annual comparison of the elevations of the two lakes from 1890 to 1910. Whence it was shown that the change of Lake St. Clair had been 89 per cent. of the change of Huron, instead of 66 2/3 per cent. as testified to by the complainant's witness.

Column 1 gives the numbers of the group; Column 2, the observed change of Lake Huron from its mean position as

previously defined; Column 3, the observed change of St. Clair from its mean position; Column 4, the change of St. Clair from its mean position, assuming that change to be 89 per cent. of the Huron change. Column 5, the difference between the observed change and the computed normal change, the normal change being 89 per cent. of that of the change in Huron. Column 6, the corrections to the discharge due to the variation of Lake St. Clair from its normal position, being the increment, minus 12,000 cubic feet per second, for the effect of one foot rise on Lake St. Clair upon the discharge of the St. Clair River, multiplied by the difference in Column 5.

Column 7 gives the observed discharge for the periods in question, which has been taken from Table 34, and Column 8 presents the discharge corrected for St. Clair in its normal position.

Table 39 corresponds to Table 33, and Column 1 presents the numbers of the group; Column 2 the mean daily elevation of Lake St. Clair; Column 3 the corrected discharge; Column 4 the multiplier, being the number of days included in each period; Column 5 the product of the discharge by the multiplier; Column 6 the mean daily elevation of Lake Huron; Column 7 the product of the mean daily elevation of Lake Huron multiplied by the multiplier in Column 4; Column 8 the centers of gravity of the weighted discharges; Column 9 the centers of gravity of the weighted elevations of Lake Huron. Whence it is seen that, subtracting the lower center of gravity for Column 8 from the upper center of gravity in the same column, there is a change of 10,417 cubic feet per second, and the change of elevation corresponding to this change, is found by subtracting the lower center of gravity in Column 9 from the upper center of gravity in the same column, to be .0368 foot. And the increment therefore derived is shown at the foot of Table 39, 28,307 cubic feet per second, which is within 575 cubic feet per second of the increment previously derived by a similar process of reasoning from the observations of 1899 to 1902, inclusive, as shown on Table 33 of Exhibit 34.

The shorter range, both in time and stage for this last series, and the possible criticism that the combination of observations at two sections may involve errors in the derived increment, leads me to consider these last computations as in the nature of checks upon the accuracy of the work of 1899 to 1902, and upon the reasonableness of the increment derived from those gagings, as presented in Table 33 of 28,872 cubic

feet per second, as being the most probable increment of the St. Clair River that has yet been derived. And as in future investigations of the problems involved, it will be desirable to be able to use the increment of Lake Huron as separate from the increment of Lake St. Clair, we proceed to obtain the increment for one foot change of Lake Huron, other conditions remaining unchanged, as follows: The net increment for the river as just obtained—28,872 cubic feet per second—when increased by the effect of back water from Lake St. Clair, due to one foot rise of Huron, or by .89 times 13,000, gives as the increment of the St. Clair River due to a rise of one foot in Lake Huron, assuming that Lake St. Clair does not change its position, 40,442 cubic feet per second.

Table 40 of Exhibit 34 gives at the top, on the left-hand side, the equation of discharge of the St. Clair River as derived by the investigations heretofore, and is: The discharge of the St. Clair River equals (Huron elevation minus 580.70), times 40,442 minus (St. Clair elevations minus 575.36), times 13,000 plus 197,610, being in cubic feet per second.

Column 1 in this table gives the year in question and also underneath the average discharge of the river for that year, as computed by the equation at the top of the page.

The second column gives the months; the third column gives the mean elevation of Huron for the months; the third column gives the rise or fall of Huron above or below its mean position; rises being designated as plus, and falls as minus. Column 5 gives the increased or decreased discharge due to the position of Huron. Column 6 gives the mean elevation of Lake St. Clair. Column 7 gives the rise or fall of Lake St. Clair above or below its mean position. Column 7 gives the decrease due to the position of Lake St. Clair. Column 8 gives the net increase of discharge over the normal discharge, or the discharge at mean position of 197,610. And the last column gives the monthly discharge as computed by the formula.

This table covers the years from 1900 to 1907, inclusive; and at the bottom of the second page of the said table is given the mean discharge from 1900 to 1904, as 191,023 cubic feet per second, and at the bottom of the third page of the table the mean discharge from 1900 to 1907 as 197,633 cubic feet per second.

The mean discharge by the complainant's equation, as shown on Table 20 of Exhibit 34, for the period from 1900 to 1904, is 188,787 cubic feet per second; and from 1900 to 1907, inclusive, as shown on the same table, is 193,528; the

discharges computed by the defendant's equation being for the shorter period, about 2,300 cubic feet, and for the longer period, about 4,000 cubic feet per second, greater than those shown by the complainant.

Adjourned to Monday, March 24, 1913, at 10:00 a. m.

Monday, March 24, 1913, 10:00 a. m.

Met pursuant to adjournment.

Present same as before.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Mr. Adcock: Have you made any calculations from, or examination of the records of the discharge measurements of the St. Lawrence River; and have you made any comparison between the records of such discharge measurements and those of any other of the rivers mentioned?

A. I have.

Q. Will you state the results of such examination and comparison?

A. The increment of the St. Lawrence River is given on Complainant's Exhibit 2 as 28,870 cubic feet per second for one foot change of stage of the St. Lawrence River referred to the Ogdensburg gage. If this quantity be computed mathematically on the assumption that the discharge curve is a straight line, and all observations are given equal weight, the value of the increment is found to be 29,230 cubic feet per second.

When, however, the observations are grouped chronologically, as is done in Table 41 of Exhibit 34 in which the observations have been grouped into six groups, varying from four to 23 observations in a group, and the mean discharges, and mean lake elevations of each group have been weighted according to the number of days covered by each discharge, in a manner similar to that which has already been explained with reference to the observations on the St. Clair River, the results are grouped in Table 42 in which the first column presents the number of gagings; the second, the number of the group; the third column, the number of days covered by each group; the fourth column, the mean daily stage at Ogdensburg; the fifth column ,the multiplier by which stage and discharge are multiplied, being the number of days included in

the group. Column 6 presents the product of the elevation by the multiplier; Column 7, the centers of gravity of the elevations; Column 8, the discharges as observed; Column 9, the multiplier, being again the number of days in each group; Column 10, the product of the discharge by the multiplier; Column 11, the centers of gravity of the discharge.

Whence, taking the lower center of gravity of Column 7 from the upper center of gravity of the same column, we have a range of 1.029 foot, on the gage at Ogdensburg, representing a change of discharge determined by subtracting the lower center of gravity in Column 11 from the upper center of gravity in the same column, giving 32,844 cubic feet per second.

Whence, dividing the change in discharge by the change in elevation, we get the increment as 31,918 cubic feet per second for one foot change in stage of the elevation of the St. Lawrence River at Ogdensburg.

The fluctuation of the Ogdensburg gage, that is, its variation in rise and fall, is approximately 95 per cent. of that of the Oswego gage, which is at the foot of the lake itself; the Ogdensburg gage being about 60 miles down the St. Lawrence River, which is, however, through this region wide and deep; and may be looked upon as practically an arm of the lake.

It, therefore, follows in view of the fact that the increment varies inversely as the fluctuation, that the increment when referred to the Oswego gage would be approximately .95 of 31,918 or 30,322 cubic feet per second.

For the period from 1900 to 1907, inclusive, the average discharge of the St. Lawrence River, by the complainant's equation, has been computed in Table 43, the elevation of the Ogdensburg gage being taken from the report of the International Waterways Commission on the regulation of Lake Erie, dated 1910, being presented in Table 14, on page 97 of the said report. From this table as shown on the same, the mean discharge from 1900 to 1907 inclusive, was 247,762 cubic feet per second. For the same period the discharge of the Niagara has been computed and is presented in Table 11 for the Bridge Section, and in Table 12 for the Open Section, the discharges being computed by the complainant's equation, using the height of the Buffalo gage as indicated in the Report of the International Waterways Commission on the Regulation of Lake Erie for 1910, and shown in Table 11, page 94 of the said report.

The average discharge of the Niagara River by the complainant's equation for the Bridge Section as derived from

the observations at the Bridge Section, is 201,436 cubic feet per second. The average discharge for the Niagara River, as derived from the complainant's equation from the Open Section, is 198,708 cubic feet per second, showing a difference of about 2,700 cubic feet per second.

For the purposes of the present investgation, that is, of the relations between the discharges and increments of the several rivers, as shown by the complainant's evidence, a mean of the average discharges of the Niagara River at two sections has been used, which is 200,072 cubic feet per second. For the same years—1900 to 1907, inclusive—Table 20 gives the discharge of the St. Clair River computed by the complainant's equation; the reference being to the gage at Harbor Beach, which is shown upon Exhibit 26. The mean discharge is found to be, as shown on Table 20, 193,528 cubic feet per second. Comparing the figures for the mean discharge of the St. Lawrence with those for the mean discharge of the Niagara, it appears that approximately 81 per cent. of the discharge of Lake Ontario came from Lake Erie, or 200,072 divided by 247,762 equals 0.81, nearly.

From 1860 to 1903, a period previous to the construction of the Gut Dam, so-called, which according to the complainant's testimony in file 6 at page 21 of the original record, being page 479 of the continuously paged record, disturbed the relation causing a rise of Lake Ontario due to a reduction of the discharge of the St. Lawrence River on account of obstruction of one of its channels. The fluctuations of Lake Ontario or the annual changes of elevation, or more properly the changes of mean annual elevation, when compared with those of Lake Erie as shown on Table 44, are found to be 44.6 per cent. greater than those of Lake Erie. Remembering the principle that the variation of elevation of the water in a reservoir is inversely as the magnitude of the increment, if the same quantity of water were delivered through both the Niagara and the St. Lawrence Rivers, we would expect the increment of the Niagara to be 44.6 per cent. greater than the increment of the St. Lawrence. But in view of the fact that only 81 per cent. of the water of the St. Lawrence, according to the complainant's evidence, comes from the Niagara River, it is to be expected that approximately 81 per cent. of the fluctuation of Lake Ontario is due to the water received from Niagara, and therefore it would be expected that the changes in Ontario corresponding to or comparable with the changes in Erie, would be 81 per cent. of 144.6 per cent., or 117 per cent. of the changes in Erie.

If, then, the increments are inversely proportional to the changes of elevation, and if the increment of the St. Lawrence River is 30,322 cubic feet per second, as deduced from the chronological groupings of the complainant's gagings on Table 42, when reduced to the Oswego gage, as already explained, it is to be expected that the increment of the Niagara must be 1.17 times as great, or about 35,480 cubic feet per second.

Proceeding now to a similar comparison of the fluctuations of Lake Erie and Lake Huron, we find, first, comparing the average discharges of the St. Clair and Niagara Rivers, that according to the testimony of complainant's witnesses, about 96.7 per cent. of the water discharged from Niagara comes from the St. Clair River, or that the quantity discharged by the St. Clair River into Lake Erie is about 96.7 per cent. of that purporting to be discharged by the Niagara River; that is to say, 193,528 cubic feet per second, the average discharge of the St. Clair River divided by 200,072 cubic feet per second, the average discharge of the Niagara, gives approximately 0.967.

Q. The discharge of the Niagara referred to, according to the discharge measurements?

A. Yes, the discharge of the Niagara being the mean of the discharges computed from the complainant's equations for the Bridge and Open Sections on the Niagara River, for the period from 1900 to 1907, inclusive.

For the period from 1860 to 1889, inclusive, the changes of mean annual stage of Lake Erie, when compared with the same for Lake Huron, as shown in Table 21 of Exhibit 34, the right-hand portion of the page shows that the changes of mean annual stage of Lake Erie have been about 75 per cent. of the changes of mean annual stage of Lake Huron for the period in question. However, as already pointed out, an examination of the relations of the lake stages indicates that about 1890, or 1889, there was a marked change of some sort in the conditions affecting lake stage, and since 1890, that is from 1891 to 1910, as shown in the right-hand bottom portion of Table 21, the changes in Lake Erie have been 85.5 per cent. of those in Lake Huron.

The method of derivation of this information, as shown on Tables 21 and 44, has been to plot the simultaneous mean annual elevations of the lakes in question and to derive the equation for the straight line which most nearly fits those elevations, by the center of gravity method. So that we have in Column 9 of Table 21, the three centers of gravity for the ele-

vations of Lake Huron; and in Column 11, the three centers of gravity for the elevation of Lake Erie. Subtracting the bottom from the top center of gravity in each case, and dividing the average change of elevation of Erie by the average change of elevation of Huron, we get the percentages in the lower right-hand corner of Table 21; and similarly, with reference to Ontario and Erie in Table 44, Column 4 gives the centers of gravity of the elevations of Lake Erie, and Column 6 the centers of gravity of the elevations of Ontario, and dividing the difference of the top and bottom centers of gravity for Ontario by the difference for Erie, we get 144.6 per cent. as indicated in the lower right-hand corner of the table, for the relation of the changes of mean annual elevation of Lake Ontario and the similar changes of Lake Erie.

In Table 21, it will be noticed that the year 1890 has been omitted. This has been done because apparently there were greater changes in conditions during the year 1890, that seeming to be a part of a transition period from the conditions of the period of the previous 30 years to the conditions of the following 20 years, and the year in which changes seemed to be taking place most prominently.

As the discharge observations submitted in the complainant's testimony have all been taken since 1891, the relations for the later period are utilized, and it is to be expected that inasmuch as 96.7 per cent. of the water discharged by the Niagara River, is represented by the inflow from the St. Clair River, that 96.7 per cent. of the fluctuation of Lake Erie would be due to that supply, approximately, or that the fluctuations of Lake Erie which correspond to the fluctuations of Lake Huron would be as 0.967 times 0.86 equals 0.83. And referring again to the principle that the fluctuations are inversely as the increment, it would be expected that since the fluctuations of Huron are greater than the fluctuations of Erie, that the increment of the St. Clair River should be 83 per cent. of the increment of the Niagara River. And taking the value of the increment of the Niagara River, which is deduced from the St. Lawrence, of 35,480 multiplying by 0.83, we get 29,450 cubic feet per second as the increment of the St. Clair River, assuming the increment of the St. Lawrence to be correctly determined and deriving it therefrom by means of the fluctuations of the intervening lakes, and Lake Huron.

If instead of the discharges from the complainant's equation, we use those of the St. Lawrence and St. Clair Rivers

from the equations submitted by the defendant, the result is as follows:

By Table 43-A, defendant's equation for the St. Lawrence, the mean discharge of the St. Lawrence River for the period from 1900 to 1907 is 248,721 cubic feet per second. Using the Niagara discharge as before, 200,072 cubic feet per second, as derived from the complainant's equations, it represents 80.2 per cent. of the flow of the St. Lawrence; and combining this with the relation of fluctuations, the ratio of the increments of the St. Lawrence and Niagara become 0.802 times 1.446 equals 1.16 and the increment of the Niagara then becomes 1.16 multiplied by 30,322 equals 35,200 cubic feet per second, or approximately the same as before.

The mean discharge of the St. Clair River from 1900 to 1907, based upon the equations of the defendants is 197,633 cubic feet per second, which is 98.8 per cent. of the Niagara discharge. And we would then expect the St. Clair increment to be, taking into consideration the percentage of discharge coming from the St. Clair River and the ratio of the fluctuations, 0.988 times 0.85 equals 0.84, multiplied by 35,200, the increment of the Niagara as just deduced, equals 29,600 cubic feet per second.

As will be shown later, the increment of the St. Clair River appears to have been increasing during the period from 1891 to 1907, and as the fluctuation relation is deduced for the average condition of the period from 1891 to 1910, it follows that at the present time the Erie fluctuations will be more nearly those of Huron, and the increment of the St. Clair therefore somewhat larger than for the average condition of the period. And hence it is concluded that the value which is derived of 29,600 cubic feet per second for the increment of the St. Clair River is somewhat low.

Comparing this value of 29,600 cubic feet per second for the St. Clair River derived from the St. Lawrence gaging, and the fluctuations of the intervening lakes and Lake Huron, with that of 28,872 cubic feet per second, as deduced from Table 33 from an examination of the measurements of the complainant by periods of consecutive stage, the coincidence of the two values, the one being derived from the St. Clair gagings, without reference to any others, and the other being derived from the St. Lawrence gagings, using only the St. Clair gagings to determine the quantity of water flowing, seems to me to be a remarkable coincidence if based on any but a rational procedure.

In this connection, attention is to be called to the fact that this computation gives an increment for the Niagara River entirely out of harmony with anything presented in the testimony of the complainant. The increment based upon the discharge at the International Bridge Section, as presented by the complainant, is 21,900 cubic feet per second, and as based upon the observations at the Open Section, as presented by the complainant, is 21,640 cubic feet per second; but by this comparison which, starting from the St. Lawrence and concerning which work in his testimony the complainant has raised no suspicion, and checking by the increment derived from the St. Clair, a similar process of derivation being used on the two rivers, and all the intrinsic evidence of the observations indicating that the discharges as measured on the St. Lawrence and the St. Clair are the more accurate of those presented, an increment is obtained for the Niagara of over 35,000 cubic feet per second, or something over 60 per cent. greater than the increment presented by the complainant.

I would in this connection refer to the testimony of complainant's witness Shenehon, folio 7, at pages 50-51 of the original record, being pages 598 and 599 of the continuously paged record, where the witness referring to the fact as testified to by him that the variations of Lake Erie are 70 per cent. approximately of those of Lake Huron is asked this question: "Q. Why isn't there just as much of an effect in Lake Erie as there is in Lakes Huron and Michigan? Why is it 70 per cent. or any other per cent.? A. It is 70 per cent. because the observations show that the thing is running that way." "Q. But do you have any reason for it except that you have noticed that it was a fact? A. I have stated that the reason, I think, the controlling reason, is the fact that the increment in the St. Clair River is really smaller than the increment in the Niagara River. Let me make that clear: In the case of small pools where the reservoir effect does not enter so largely, and we can see the thing very much more clearly, if we know the increments of two pools, as for instance the Whirlpool, and the pool in the Niagara River above the Rapids, above the cataract; if we know that the increments are in the ratio of 2.50 to 0.56, we know very well that the fluctuations would bear the inverse ratio. It is not entirely certain that when you take large reservoirs like Lakes Michigan, Huron and Erie, that you can—rather, it is very certain that you cannot—argue with the same certainty that you would in the case of these smaller pools. The local supply, local run-off, local

evaporation, those elements are likely to enter in, and I do not want to state, on the face of that, clearly, that I know the increment in the St. Clair River is smaller than it is in the Niagara River; but I think it is a clear proposition."

It therefore appears that the deductions of the previously described investigation as to the relations between the increments of the St. Lawrence, Niagara and St. Clair, are corroborated by the inner consciousness of the complainant's witness, although contradicted by the physical facts of the complainant's gagings.

Mr. Wilkerson: I will move to strike that out as argumentative.

The Witness: The Niagara gagings, when referred to the mean daily gage height on the Buffalo Gage, and treated by chronological grouping as shown in Table 45, give an increment of 27,336. The construction of this table is exactly similar to that of the table for the St. Lawrence, and the two tables that were similarly constructed for the St. Clair. The table of preliminary groups has not been included in the exhibit, but will be furnished to the complainants for inspection if they so desire.

The Buffalo Gage is situated at the east end of the lake near its outlet, and is undoubtedly the gage which controls most nearly the discharge of the river. It is not the gage, however, by which the mean elevation of the lake is established, as the record of the Cleveland Gage has been accepted for that purpose, I think for two reasons; one, that there was some question as to the early accuracy of the elevation of the Buffalo Gage, and the other, that the Cleveland Gage being situated near the middle of the lake, is less affected by the fluctuations of surface due to wind than would be a gage at either end.

If the elevation of Lake Erie be established by the mean of the gage at Buffalo at the east end of the lake and the gage at Amherstburg, at the foot of the Detroit River at the west end of the lake shown on Table 46, the increment becomes 28,359 cubic feet per second. And if the Cleveland Gage be used, as shown on Table 47, the increment becomes 32,060 cubic feet per second.

Lake Erie is noted for its violent fluctuations, due particularly to wind effects, which on account of the shallowness of the lake preventing the free flow of the return currents, causes the water to pile up at one end or the other as the direction of the wind may be; and there exists a

continual surging from end to end due to these wind effects and barometric changes. This contributes largely to the difficulty of accurate measurement of the discharge from this lake. The swiftness of the current at the gaging station, and the always accompanying pulsations of swift running water, together with the depth of the measuring section, all introduce elements affecting the absolute accuracy of any current meter gaging. And while at the Bridge Section the possibility of working from a rigid platform afforded a noticeable advantage over any of the other sites, this was to a large extent counteracted by the irregular currents set up as the water passed the piers, its flow being disturbed and eddy motions created, which may lead to very serious errors in current meter work.

Furthermore, the fact that there is a fall of about five feet between the lake and the gaging section tends to obscure to a considerable extent the effects of changes in the lake, so that bearing in mind that when the discharge from a reservoir whose surface is fluctuating is measured, while the discharge itself may be accurately measured, the increment derived from those discharges will necessarily be too small by reason of the fact that the discharge does not increase or decrease as rapidly as the elevation of the lake surface changes.

Considering all these elements as affecting the gagings at the Niagara River, as well as the evidence of the comparisons of those gagings, already discussed and presented in Tables 9 and 10 of Exhibit 34, it is not surprising to me to find that the results of these observations do not harmonize with those of the other two rivers; and it is my belief that the value of the increment, 35,000 cubic feet per second, derived from the St. Lawrence and St. Clair discharges and the lake stage correlations covering a long period of years, is more nearly correct than that deduced from the Niagara gagings, which covered only a brief period of time, and were subject to many very difficult conditions.

At this time I want to say that my criticism of the Niagara work is a criticism of the conditions and not of the work which was done, for it is my belief that there is nowhere on record a more painstaking example of experimental work in the nature of stream gaging, than that which is exhibited in the record of the Niagara gagings.

In this connection, I would refer to the Report of the International Waterways Commission, being Exhibit 33, Report of the International Waterways Commission on the Regula-

tion of Lake Erie, 1910, where it is stated in paragraph 147, page 81:

"Artificial storage of water in Lake Superior between December, 1888, and December, 1907, inclusive, by the placing of obstructions in the upper St. Mary's River, has had the effect of raising the mean stage of Lake Superior by about 0.87 foot in 1904 and of lowering Lakes Michigan, Huron, Lake Erie and Lake Ontario by the maximum of 0.15, 0.12, 0.10 foot respectvely."

What I would call particular attention to here is the fact that the lowering of Lake Erie is placed intermediate between that of Lake Ontario and Lake St. Clair, and indicating a ratio between the increments of the St. Clair River and the Niagara of 15 divided by 12 or 1.25 per cent. If this relation were correct, and the increment of the St. Clair River be as assumed and computed by the defendant, 28,872 cubic feet per second, the increment of the Niagara would be a little over 36,000 cubic feet per second.

Mr. Adcock: Have you made any examination of the complainant's discharge equations with reference to the physical conditions of the Great Lakes?

A. I have.

Q. Will you state the result of such examination and the different steps by which you reach the result which you claim to be the correct result; and give the basis for your conclusions?

A. The complainant's discharge equations, and the results to be derived from them have been examined with a view to testing the accuracy of the experimental conclusions by applying the results to the physical conditions to which they are related on the Great Lakes. And for the purposes of such a comparison, the hydraulics and hydrography and hydrology of the Great Lakes system have been examined in the light of the complainant's discharge equations.

The preliminary examinations embraced a comparison of the discharges from 1900 to 1907, inclusive, when, as before stated, by the complainant's equation as presented in Table 43, the mean discharge of the St. Lawrence River was 247,762 cubic feet per second. The total land drainage tributary to the St. Lawrence River, being the land drainage areas of all the Great Lakes, based upon the Report of the International Waterways Commission on the Regulation of Lake Erie of 1910 and presented there, or derivable from the table presented on page 9 and designated as Table "A," by subtract-

ing the area of the lake surface from the drainage area including lake surface, given in the said table, is found to be 192,600 square miles.

Mr. Wilkerson: Let me make a statement, Mr. Commissioner, about this report of the International Waterways Commission on the Regulation of Lake Erie for 1910. It is understood that this document, as it is referred to in connection with the testimony of this witness and other witnesses, is to be treated in evidence to the extent that either side, in either the direct examination of the witness or the cross-examination of the witnesses, may refer to such portions of it as may be deemed pertinent to the inquiry; that being for the purpose of avoiding the necessity of copying the entire document into the record.

Mr. Adcock: And offer in evidence such portions as you may refer to.

Mr. Wilkerson: Each side will indicate such portions as they want. It may be before we get through with the discussion that the whole document will have to go in.

The Witness: The discharge of the St. Lawrence River as given above 247,762 cubic feet per second is equivalent to a run-off from this land drainage area of 192,600 square miles of an average of 1.28 cubic feet per second per square mile.

If we take the total drainage area, including the lake surfaces tributary to the St. Lawrence River, which is, as shown in the report of the International Waterways Commission on the Regulation of Lake Erie, 1910, in Table "A" on page 9, 287,688 square miles, the average run-off per square mile represented by the discharge of the St. Lawrence River for this entire drainage area is 0.861 cubic feet per second.

Taking for the Niagara the mean discharge of the Open and Bridge Section equations for the period from 1900 to 1907 inclusive, 200,072 cubic feet per second, and from the table on page 9 of the Report of the International Waterways Commission, the land drainage tributary to the Niagara River derived by a simple process of subtraction as 166,863 square miles, the above discharge of the Niagara is equivalent to a run-off per square mile of 1.2 cubic feet per second from this land drainage.

The total drainage area including the lake surfaces tributary to the Niagara River, from the aforesaid authority, is 254,708 square miles, and the discharge of the Niagara River as presented by the equations of the complainant therefore

represents a run-off of 0.785 cubic feet per second per square mile for the total drainage area above it.

The discharge of the St. Clair River from 1900 to 1907, as computed from the complainant's equation in Table XX, is 193,528 cubic feet per second; the land drainage tributary to the St. Clair River, as shown in the table of the Report of the International Waterways Commission, above referred to, is 136,567 square miles, and the above discharge is equivalent to an average run-off per square mile from this land drainage of 1.42 cubic feet per second.

The total drainage area of the St. Clair River is 213,941 square miles, and the average run-off from this total drainage, as represented by the above computed discharge of the St. Clair River from the complainant's equation is 0.905 cubic feet per second per square mile.

The St. Mary's River has not been introduced into this case as yet, but as the conditions of run-off and evaporation may be appreciably different upon Lake Superior from those on Lakes Huron and Michigan, for the sake of following this process of investigation to the end, the average discharge of the St. Mary's River from 1900 to 1907 has been taken from the Report of the International Waterways Commission upon the Regulation of Lake Erie, the same being shown on page 101, being marked Exhibit 33-F. This average discharge from 1900 to 1907 of the St. Mary's River is found to be 78,-200 cubic feet per second. The land drainage tributary thereto, from the report of the International Waterways Commission, is 44,074 square miles, and the above discharge is equivalent to an average run-off of 1.78 cubic feet per second per square mile for the land drainage.

The total drainage tributary to the St. Mary's River is 76,-134 square miles, which gives as the equivalent of the above discharge, an average run-off per square mile of 1.028 cubic feet per second, from the entire drainage area.

It will be noticed in passing that the run-offs per square mile show a progressive increase both for the land drainage and the total drainage, from the St. Lawrence to the St. Mary's, with the exception of Niagara, which shows a reduction of average run-off from its drainage area.

We next consider the evidence of local discharge, and by local discharge we mean that portion of the river which comes from the drainage area between it and the river next above. The local discharge of the St. Lawrence would then be represented by the difference in the discharge of the St. Law-

rence and Niagara River; and the local discharge of the Niagara would be represented by the difference between the Niagara and the St. Clair; and the local discharge of the St. Clair would be represented by the difference between the discharge of the St. Clair and the St. Mary's Rivers. And in the case of the St. Mary's, the total discharge and the local discharge would coincide. Subtracting from the discharge of the St. Lawrence, the discharge of the Niagara above, as previously computed from the complainant's equations, the former being 247,762 cubic feet per second, and the latter 200,072 cubic feet per second, the difference is 47,690 cubic feet per second, which represents the discharge due to the drainage area of Lake Ontario, and so much of the Niagara River as is below the gaging station at which the discharge of the Niagara River was measured.

Similarly, subtracting from the discharge of the Niagara River 200,072 cubic feet per second, the discharge of the St. Clair River, 193,528 cubic feet per second, there remains as the discharge from the drainage area of Lake Erie and St. Clair, and so much of the Detroit and St. Clair Rivers as are below the gaging station on the St. Clair River, 6,544 cubic feet per second.

Subtracting from the discharge of the St. Clair River 193,-528 cubic feet per second, the discharge of the St. Mary's River as derived from the Report of the International Waterways Commission 78,200 cubic feet per second, it leaves as the discharge from the drainage areas of Lakes Michigan-Huron, and so much of the St. Mary's River as is below the point of gaging on the said river, 115,326 cubic feet per second.

Referring again to Table "A," page 9, of the Report of the International Waterways Commission upon the Regulation of Lake Erie for 1910, the land drainage tributary to Lake Ontario and so much of the Niagara River as lies below the point of gaging of the Niagara, is 25,737 square miles. The excess of run-off of the St. Lawrence River over that of the Niagara, 47,690 cubic feet per second, then is equivalent to a run-off from this land drainage, of 1.85 cubic feet per second per square mile. Similarly the land drainage of Lakes Erie and Ontario, and so much of the Detroit and St. Clair Rivers as lie below the point of gaging on the St. Clair River, is shown by the above authority to be 30,296 square miles, and the excess of discharge of the Niagara River over that of the St. Clair River 6,544 cubic feet per second is equivalent to a run-off from this land area of 0.216 cubic feet per second per

square mile, or about 1/9 of the amount that runs off, apparently, from the watershed of Lake Ontario.

From the Report of the International Waterways Commission it appears that the land drainage tributary to the St. Clair River, on Lakes Michigan and Huron and so much of the St. Mary's River as lies below the gaging station for that river, is 92,493 square miles, and the difference in discharge between the St. Clair and St. Mary's Rivers 115,328 cubic feet per second is equivalent to a run-off from this land drainage of 1.25 cubic feet per second per square mile, or about six times as great as that appearing from the Lake Erie drainage, and about 2/3 as great as that appearing from the St. Lawrence drainage.

If instead of taking the land surfaces only upon these drainage areas we take both the land and water surfaces which are given directly in Tables "A," page 9 of the Report of the International Waterways Commission on the Regulation of Lake Erie for 1910, we find that the total drainage tributary to the St. Lawrence River below the point of gaging of the Niagara River to be 32,980 square miles, the difference between the St. Lawrence and Niagara discharges, 47,690 cubic feet per second, for this area is equivalent to an average run-off of 1.45 cubic feet per second per square mile, for the Ontario drainage. The total drainage including lake surface tributary to the Niagara River between the point of gaging on that river and the point of gaging on the St. Clair River is obtained from the aforesaid report to be 40,767 square miles, and the difference of the Niagara and St. Clair discharges, 6,544 cubic feet per second is equivalent to an average run-off upon the drainage area of Lake Erie and Lake St. Clair and so much of the Detroit and St. Clair Rivers as are below the point of gaging of the St. Clair River of 0.16 cubic feet per second per square mile, or, again about 1/9 of that of the St. Lawrence.

The total drainage area of Lake Huron and Michigan including the lake surfaces is found from the aforesaid authority to be 137,807 square miles, and the difference of discharge between the St. Clair River and the St. Mary's Rivers 115,328 cubic feet per second, is equivalent to an average run-off of 0.84 cubic feet per second per square mile for the entire Michigan-Huron drainage, or something over five times as much as that from the drainage area of Lakes Erie and St. Clair.

In order, if possible, to check the probable accuracy of the derived figures of run-off from the several lake basins, an

examination was made of the records of the discharges of rivers as presented in the reports of the United States Geological Survey, of the State Engineer of New York, and of the Report of the Board of Engineers on Deep Waterways, and of unpublished data of the London-Ontario Water Works, and of numerous gagings of rivers in Michigan, mainly from my individual experience, and taking all the information that we were able to find, but probably not all that exists, there was deduced therefrom an average run-off per square mile for each month, and these were combined into an average annual run-off for the drainage area tributary to each lake. For Lake Ontario gagings were found representing 37 per cent. of the drainage area; and the average run-off per square mile of these gagings per year was 1.44 cubic feet per second. For Lakes Erie and St. Clair gagings were found representing 33 per cent. of the drainage areas, and the average run-off from these drainage areas as shown by those gagings was 0.66 cubic feet per second per square mile. For Lakes Huron and Michigan gagings were found covering about 32 per cent. of the drainage areas, and showing an average run-off of 0.85 cubic feet per second per square mile.

Comparing these results with those previously deduced for the average run-off from the entire drainage areas of the lakes taken separately, it is seen that whereas in the first computation, the average run-off of the drainage area of Lake Ontario, including the lake surface as derived from the difference between the Niagara and St. Lawrence discharges, was 1.45 cubic feet per second, the average run-off per square mile as derived from the streams tributary to Lake Ontario was 1.44 cubic feet per second, and, whereas, the average run-off from the land and water surface tributary to the St. Clair River, exclusive of Lake Superior drainage, was 0.84 cubic feet per second, the average run-off indicated by the stream gagings tributary to Lakes Huron and Michigan was 0.85 cubic feet per second, while for Lake Erie from the difference of discharge between the Niagara and St. Clair Rivers, the average run-off from the total drainage tributary to Lakes Erie and St. Clair exclusive of that coming from Lakes Michigan, Huron and Superior, was 0.16 cubic feet per second, the average run-off indicated by the streams gaged tributary to Lakes Erie and St. Clair was 0.66 cubic feet per second, or about four times as much.

The result of this comparison for the drainage area upon Lake Erie being so far out of harmony with the results for

the drainage areas of Ontario and Michigan-Huron led to a further examination to ascertain if it were possible to account for the very remarkable difference which exists between the apparent run-off per square mile from the drainage area of Lake Erie as indicated by the outflow of the Niagara River upon the complainant's figures, and the average run-off from the same drainage area as indicated by the gagings of streams representing about one-third of that drainage area.

Mr. Wilkerson: I move to strike out the answer thus far made and each statement in it on the following grounds: That in each one of the statements of the answer there are assumptions which are wholly unsupported by anything in the record in this case, or in the evidence in the case; as well as references to facts, which nowhere appear from any portion of the record or the evidence in this case.

(In connection with the objection made by the Government's counsel the witness states that he will produce for such examination as may be desired to be made of the same, the different items of facts which he has used as the basis of his computation; and if desired will present the same as an exhibit.)

Recess until 2 o'clock p. m.

After Recess—2 p. m.

GARDNER S. WILLIAMS resumed the stand and testified as follows:

The Witness: My attention having been directed to the apparently abnormally low run-off from the drainage area of Lake Erie and Lake St. Clair, I then proceeded to examine the question in more detail, by reference to the discharges for the period from 1900 to 1904; my reason for selecting this period being that it was the period covered, or most nearly covered, by the drainage measurements which have been presented in this case; and it also avoided the interference with the levels of Lake Ontario due to the construction of the Gut Dam, to which reference has already been made.

The average discharge of the St. Lawrence River by the complainant's equation, as shown on Table XLIII for the period from 1900 to 1904, inclusive, is 240,820 cubic feet per second.

The mean discharge of the Niagara River by the average

of the two equations of the complainant, that at the Bridge Section being 198,068 cubic feet per second, and that at the Open Section 195,390 cubic feet per second, as shown in Tables XI and XII for the period from 1900 to 1904 is 196,739 cubic feet per second.

Complainant's witness Wheeler, file 4 at page 70, being page 166 of the continuously paged record, states the diversion through the Erie Canal to be 1,200 cubic feet per second, and that through the Welland Canal to be 1,100 cubic feet per second, and adding these to the average of the discharges of the Niagara River as just stated, makes a total of 196,739, plus 2,300 equals 199,039 cubic feet per second. Subtracting this discharge from Lake Erie from the discharge from Lake Ontario, we have 240,820 minus 199,039 equals 41,781 cubic feet per second as the quantity contributed from the drainage area of Lake Ontario.

The drainage area of Lake Ontario, exclusive of the lake itself, is, as already stated, 25,737 square miles, and the average run-off per square mile of the streams on which gagings are recorded, which embrace about 37 per cent. of the drainage, and which gagings are of record in the reports of the United States Geological Survey, State Engineer of New York and in some other sources which will be presented for the examination of the complainant, is 1.44 cubic feet per second.

Assuming the 37 per cent. of the area covered by the runoff records to be representative of the whole drainage, the land drainage would contribute to Lake Ontario 37,061 cubic feet per second, being the product of the area, 25,737 square miles by 1.44 cubic feet per second, being the run-off per square mile. Subtracting 37,061 cubic feet per second from the land surface from the run-off from the entire Ontario drainage, as computed above, 41,781 cubic feet per second, leaves to be contributed by rainfall on the lake surface, and subterranean supply, if any, 4,720 cubic feet per second.

The average precipitation at the several United States and Canadian Weather Bureau Stations on the shores of Lake Ontario for the years in question was 35.78 inches. The records of these stations, from which this figure is obtained, will be furnished to the complainant. The area of the surface of Lake Ontario is, as already stated, 7,243 square miles, and the average rainfall when reduced to cubic feet per second, being the product of the 35.78 inches multiplied by 7,243 square miles, and reduced by dividing by the proper factor,

is therefore equivalent to a flow of 19,150 cubic feet per second.

Subtracting from this 19,150 cubic feet per second the excess of the run-off from the Ontario drainage over the run-off from its land surface, as previously computed, which was 4,720 cubic feet per second, leaves 14,430 cubic feet per second more than the run-off of the river accounts for, and this difference, therefore, represents the least amount of evaporation from the surface of Lake Ontario consistent with the premises upon which this discussion is based; which evaporation is equal to 1.99 cubic feet per second per square mile, or to 27.0 inches of rainfall on the lake.

The mean discharge of the Niagara River from 1900 to 1904 has already been stated to be 196,739 cubic feet per second. The Erie and Welland Canals, according to the complainant's witness, added 2,300 cubic feet per second, making the total outflow from Lake Erie 199,039 cubic feet per second for the average of the period from 1900 to 1904 inclusive.

The mean discharge of the St. Clair River, by the complainant's equation for the same period, is 188,787 cubic feet per second, as shown in Table XX. This leaves the amount of water to be contributed to the Niagara River by the Erie and Lake St. Clair drainage as 10,252 cubic feet per second, being the difference between 199,039 cubic feet per second flowing from Lake Erie and 188,787 cubic feet per second flowing into Lake Erie through the St. Clair and Detroit Rivers.

The drainage area of Lake Erie and St. Clair, exclusive of the lakes themselves, is 30,296 square miles, as already stated, and the average run-off per square mile of the streams on which gagings have been examined, which embrace about 33 per cent. of the drainage area, is 0.66 cubic feet per second.

Assuming the run-off as shown from this 33 per cent. of the drainage area to be representative of that from the entire drainage area, the land drainage, therefore, would contribute 30,296 times 0.66 equals 19,995 cubic feet per second, which is more than the remainder of the outflow by the difference between 19,995 cubic feet per second and 10,252 cubic feet per second, or by 9,743 cubic feet per second; and this must then disappear by evaporation from the lake surface, together with rainfall on the lake surface, and the subterranean flow, if any, basing the conclusion upon the premises already stated.

The average precipitation at the several United States and Canadian Weather Bureau Stations on the shores of Lake

Erie for the period in question was 33.77 inches; and the detail of this information will be furnished to the complainant.

The area of the lake surfaces is 10,471 square miles, and multiplying this area by the rainfall and dividing by the proper factor, the average rainfall is therefore equivalent to a flow of 26,050 cubic feet per second. This added to the 9,743 cubic feet per second of excess from the drainage area over the difference between the outflow from Erie and the inflow through the St. Clair River gives a minimum evaporation of 35,793 cubic feet per second, which is equal to 3.42 cubic feet per second per square mile of lake area, or to 46.4 inches of rainfall annually.

Coming to Lakes Michigan-Huron, the mean discharge from the St. Clair River, from the complainant's equation, has already been stated as 188,787 cubic feet per second. The mean discharge of the St. Mary's River as given in the report of the International Waterways Commission on the Regulation of Lake Erie for 1910, from 1900 to 1904, is 76,060 cubic feet per second. Subtracting the latter from the former, we have 188,787 minus 76,060 equals 112,727 cubic feet per second as the amount of water contributed from the Michigan-Huron drainage.

During this period the Chicago Drainage Canal diverted an average of 4,200 cubic feet per second, which makes a total discharge from Lakes Michigan-Huron for this period of 112,727 plus 4,200 equals 116,927 cubic feet per second.

The drainage area of Lakes Michigan-Huron, exclusive of the lakes themselves, is, as already stated, 92,493 square miles. The average run-off per square mile of the streams on which gagings are recorded, which embrace about 32 per cent. of the drainage areas, is 0.85 cubic feet per second. The detail upon which this run-off is based will be furnished for the examination of the complainant.

The land drainage, therefore, contributes 92,493 times 0.85 giving 78,619 cubic feet per second, which leaves to be contributed by the rainfall on the lake surfaces, and subterranean flow, if any, the difference between 116,927 cubic feet per second, the total outflow and 78,619 cubic feet per second, the total inflow from the land drainage, or 38,308 cubic feet per second; the assumption here being, as in the case of the other two lakes, that the run-off from the 32 per cent. of the drainage area is representative of that from the entire drainage.

The average precipitation at the several United States and Canadian Weather Bureau Stations on the shores of Lakes

Michigan-Huron for the period in question was 30.26 inches. The information upon which this is based will be submitted to the complainant. The area of the lake surfaces is 45,314 square miles. Multiplying the average rainfall of 30.26 inches into the area, 45,314 square miles of the lake surfaces and dividing by the proper factor gives an equivalent flow for the rainfall on the lake surfaces of 101,020 cubic feet per second. Subtracting from this the quantity, 38,308 cubic feet per second, which it was necessary to have contributed from the rainfall on the lake surfaces to complete the discharge from the lake, there remains 62,712 cubic feet per second more than the discharge from the lakes account for. And this difference, again, is the minimum evaporation, on the premises on which this investigation is based, which is equal to 1.38 cubic feet per second per square mile, or 18.7 inches.

The foregoing computations have not taken into account the change of stage of the several lakes, during the period considered.

Q. Why is it necessary to take that into consideration?

A. Because if the lakes raised, a certain amount of the water which has been computed as flowing in, was absorbed and stored in the lake; and if the lakes fell, an additional quantity must have flowed out beyond that which came from the land, so that if the lakes raised, then the inflow, or the amount left as evaporation, should be decreased, and if the lakes fell the amount charged to evaporation should be increased.

Between December, 1899, and December, 1904, using the monthly means, Lake Ontario raised 1.45 feet; Lakes Erie and St. Clair raised an average of 0.445 feet; Huron and Michigan raised an average of 0.542 feet; and Superior fell 0.26 feet.

This storage was equivalent to an evaporation from the lake surfaces of the amounts represented in feet when reduced to inches, which is for Ontario 3.48 inches; reducing the evaporation by that amount for Erie and St. Clair 1.07 inches, reducing the evaporation by that amount, and Huron-Michigan 1.29, reducing the evaporation by that amount.

We then have, from the previous computations, an evaporation from Lake Ontario of 27.0 inches which when reduced by 3.48 inches equals 23.52 inches; from Erie and St. Clair, by the previous computation, 46.4 inches, which when reduced by 1.07 becomes 45.33 inches and a computed evaporation from Lakes Michigan-Huron of 18.7 inches which, when reduced by 1.29 becomes an evaporation of 17.41 inches.

The evaporations for Lakes Ontario, 23.52 inches, and Michigan-Huron, 17.41 inches, vary from the mean of the two by less than 15 per cent. as above computed. The total Ontario evaporation is equal to 23.52 divided by 35.78, or 65½ per cent. of the rainfall on its water surfaces. The total Michigan-Huron evaporation is 17.41 divided by 30.26 or 57½ per cent. of the rainfall on its water surface. Assuming the complainant's testimony and the preceding computations to be correct, the total evaporation from Erie and St. Clair must be as follows——

Q. You mean the testimony which you have referred to?

A. Yes, assuming the complainant's testimony, to which reference has been made in this connection, and the computations and assumptions herein made to be correct, the total evaporation from Erie and St. Clair must be at least 45.33 minus 33.77 divided by 33.77, equals 11.56 divided by 33.77, or about 34.3 per cent. more than the rainfall on its water surface.

The Erie evaporation herein deduced as correct for the storage is nearly 2 1/5 times the mean of that of the other lakes. That the rate of evaporation from Lakes Erie and St. Clair would exceed that from the other lakes has been expected from the shallowness of the water and the effects of winds upon its surface; and by some has been attributed to the direction of its major axis, but so far as the position of its major axis is concerned, Ontario occupies a similar position, and the width of Lake Huron is nearly as great as the length of Lake Erie. Whether or not the shallowness of the water can account for an increase in evaporation of 121 per cent. is to be determined, if at all, by an examination of related data, as there are no direct observations known to me that solve the question.

In 1887 and 1888, there was carried on at the several United States Weather Bureau Stations along the Great Lakes simultaneously for a period of twelve months, with dry and wet bulb thermometers, and the Piche evaporemometer, a series of evaporation observations. These observations are published by the United States Weather Bureau in the Monthly Weather Review for September, 1888; and if desired, a transcript of them will be furnished to the complainant.

The evaporation at the Lake Ontario Stations, which were Oswego and Rochester, for the period 1887, 1888, was found to be 30.65 inches, or 60 per cent. more than the rainfall. At Lake Erie Stations it was 35.6 inches, or 20 per cent. more than the rainfall. At the Michigan-Huron Stations it was

29.37 inches, or 7 per cent. less than the rainfall. And at the Lake Superior Stations it was 23.75 inches, or about 22 per cent. less than the rainfall.

On Lake Erie, the evaporation was observed at Buffalo, Erie, Cleveland, Sandusky, Toledo and Detroit. On Lakes Michigan-Huron, evaporation was observed at Port Huron, Alpena, Green Bay, Grand Haven, Milwaukee and Chicago. On Lake Superior, evaporation was observed at Duluth and Marquette.

At the same time, evaporation observations were carried on with similar apparatus by the Weather Bureau at Boston Massachusetts. Rainfalls during this period were for Ontario, 22.49 inches; for Erie, 29.34 inches; for Michigan-Huron, 31.55 inches, and for Superior, 30.39 inches, based upon the observations at the same stations where the evaporation observations were made.

Q. What period do you refer to?

A. 1887-8.

Q. Why is it important to consider the rainfall at that time?

A. Because that has its bearing upon the evaporation. In the case of a large rainfall, it would probably mean that it was distributed over a large number of days, although not necessarily; and while it is raining there can be no evaporation. So that the evaporation would be expected to increase as the rainfall decreased, speaking of evaporation from water surfaces.

This would not hold true upon the land because the land surface would become dry, and there would be no more water to evaporate; so that on land surfaces the evaporation is likely to increase with the rainfall, up to a certain limit at least, but on the water surface, the opposite is generally true.

The evaporations for Ontario and Michigan-Huron is indicated by these observations, varied by about 4 per cent. from the mean, and the Erie evaporation exceeded that of Ontario by about 16 per cent., and that of Michigan-Huron by about 18 per cent.

These observations, while in my opinion they are not to be taken as representative of absolute quantities, I do believe them to represent relative conditions within a reasonable degree of accuracy, and that being the case it does not appear to me that they account for or even suggest the enormous evaporation from Lake Erie which is necessary to account for the discharges derived from the complainant's equations. And it therefore seems evident that there must be some other ele-

ment entering into this question of lake discharge, which has not been considered in the discussion thus far.

In this connection I would refer to the statement, Appendix EEE of the Report of the Chief of Engineers for 1904 at page 4130, paragraph 10, which is as follows:

"The average discharge of the Detroit River for 11 years, 1893 to 1903, is 193,854 cubic feet per second. The average discharge of Niagara River for the same time is 197,328 cubic feet per second. The discharge of Niagara River should be greater than the discharge of Detroit River by the quantity of water coming from the drainage area of Lake Erie. This quantity if taken as a part of the outflow through Niagara River, proportional to the area of the Lake Erie drainage area as compared with the whole drainage of the lakes above Niagara, should be 30,100 cubic feet per second. Either the Detroit River discharge, therefore, is too much, or the Niagara River discharge is too small. If there is no greater difference in the discharges of the Detroit and Niagara Rivers than the observations show, it would indicate an evaporation from the surface of Lake Erie of 81.4 inches for the year, a quantity greater than seems admissible. This assumes a run-off of .6 of the rainfall on the land part of the drainage area of Lake Erie."

This report is signed by Thomas Russell, assistant engineer, addressed to Major W. L. Fiske, Corps of Engineers United States Army.

Q. Where was he located at that time?

A. An assistant engineer in the office of the United States Lake Survey.

Q. At Detroit?

A. At Detroit.

Mr. Wilkerson: Please note the same motion with respect to the remaining portion of this discussion of this subject as was made this morning; and also on the further ground that it appears, from the testimony of the witness, that the data which are assumed as the basis of this conclusion are entirely too indefinite to furnish any foundation for any conclusion such as that which has attempted to be drawn. And I reserve the right to specify further grounds, in support of the motion to strike the discussion of the witness, after the conclusion of the cross-examination, not stopping at this time to cross-examine as to the data upon which the conclusion was based.

Mr. Austrian: You are not objecting at this time on the

ground that you have not been furnished the data that he said he would furnish?

Mr. Wilkerson: Oh, no. I reserve the right to specify further grounds when we have examined the data. But the ground that I last specified here was suggested by the comments made by the witness himself upon the data which he has used as the basis of the conclusion.

Mr. Adcock: Have you made any investigations and conclusions, with reference to the general subject of the changes in lake levels?

A. I have.

Q. Will you state the facts upon which you have made these calculations, the basis of any conclusions which you have drawn, and such conclusions as you may have drawn from such investigations and facts stated?

Mr. Wilkerson: By that you mean he is to tell what changes have taken place in the levels of the respective lakes, and then give us his theory as to why the change has taken place?

Mr. Adcock: With reference to the subject-matter of the investigation, the increment, and so forth; discharge measurements, and the increment derived from the measurements of the different rivers.

A. From Table XIX from Exhibit 34, it appears that the mean elevation of Lakes Huron-Michigan for the 30 years from 1860 to 1889, inclusive, was 581.91, and from 1890 to 1907, inclusive, it was 580.48, or 1.43 foot lower.

Similarly, during the earlier period, Lake Erie was at elevation 572.92, and during the later period at 572.08, or .84 foot lower during the latter period.

Complainant's witness Haskell, file 2, page 46, being page 64 of the continuously paged record, has attempted to explain this lowering on the grounds of deficient precipitation. Table 48 of Exhibit 34 presents the precipitation at typical stations on the various drainages, derived from the records of the United States Weather Bureau, United States Army, Smithsonian Institution, at typical stations on the various drainages. It was necessary to confine the investigation to these typical stations, because they were practically the only ones upon which continuous observations extended back over the period of years in question.

The record for Lake Superior is dependent upon the observation at Marquette; for Lakes Michigan-Huron it is based upon the observations at Milwaukee and Detroit; for Lakes Erie and St. Clair, it is based upon the observations at De-

troit, Cleveland and Buffalo; for Lake Ontario, it is based upon the observations at Buffalo, Oswego, Rochester and Toronto.

As indicated at the foot of the table for a total of six years in the group, the record of Toronto is missing; and during a short period during the three years 1867, 1868 and 1869, the record at Detroit is missing, and is supplied by taking a mean of obseravtions at Lansing and Monroe.

From the data so compiled and presented in Table 48, Exhibit XXXIV, it appears that from 1860 to 1889, as shown in that table, the average annual rainfall on Lakes Michigan-Huron was 32.35 inches; from 1890 to 1907 30.90 inches, giving an excess during the shorter period of 1.45 inches.

On Lake Erie, the average precipitation during the earlier period was 35.77 inches and during the later period 33.71 inches, a difference of 2.06 inches, of excess in the earlier period.

On Ontario, the average precipitation for the earlier period was 35.06 and for the later period 34.13 inches, showing an excess in the former period of 0.93 inches.

As the record of rainfall on Lake Superior is incomplete, in order to eliminate Lake Superior from the computation, I have taken from the report of the International Waterways Commission on the Regulation of Lake Erie for 1910, the average discharge of the St. Mary's River from 1860 to 1889, as 85,300 cubic feet per second, and from 1890 to 1907 as 76,400 cubic feet per second, showing a decrease in the second period of 8,900 cubic feet per second. During 7 of the 18 years of the second period, or 39 per cent., the Chicago Drainage Canal has been diverting an average of about 4,300 cubic feet per second, which would be equivalent to 1,675 cubic feet per second for the whole period.

The total average decrease of outflow due to the above causes, that is, the change of flow of the St. Mary's River, and the Chicago diversion, has been 10,575 cubic feet per second. That is, it is the sum of 8,900 cubic feet, decreased flow of St. Mary's River, and 1,675 cubic feet per second, flow of the Chicago Drainage Canal, which makes 10,575 cubic feet per second. And with an increment in the St. Clair River of 28,872 cubic feet, as derived in Table 33 of Exhibit XXXIV, this would account for a lowering of Lakes Huron and Michigan of 0.366 foot. Of the total lowering of 1.43 foot in Lakes Michigan and Huron, therefore, approximately 0.37 foot seems, by the above analysis, to be accounted for, leaving 1.06 foot of lowering to be charged to deficient precipitation.

Using the same increment as before, this must be due to an abstraction of 1.06 times 28,872, or 30,600 cubic feet per second, which is 30,600 divided by 197,633, or about 15.6 per cent. of the present decreased outflow. The difference of precipitation for Michigan-Huron already cited, is about 4.7 per cent. of the precipitation during the last period, so that if precipitation accounts for this lowering, we find that, reasoning conversely, an increase of precipitation of 4.7 per cent. should increase the outflow of Lakes Michigan-Huron 15.6. The reasonableness of this conclusion may be tested by a comparison with the conditions on Lakes Erie and Ontario.

The discharge of Lake Erie has been increased during the later period by increased diversions through the Erie and Welland Canals, which amount to about 1,000 cubic feet per second, so the total decrease of outflow of the Niagara River, by diversions and decreased flow in St. Mary's River, would be the sum of the decrease of St. Mary's River, 8,900 cubic feet per second, the outflow through the Drainage Canal of 1,675 cubic feet per second, and the increased diversions through the Welland and Erie Canals of 1,000 cubic feet per second, or 11,575 cubic feet per second.

Assuming an increment for the Niagara River of 34,000 cubic feet per second as derived from the comparison between the St. Lawrence and St. Clair Rivers, this would account for a lowering of 11,575 divided by 34,000, or about .34 of a foot, which subtracted from the .84 foot which Lake Erie lowered between the two periods, leaves .5 of a foot to be due to decreased precipitation.

A fall of .5 of a foot represents an abstraction, using the increment of 34,000 cubic feet per second, of 17,000 cubic feet per second. The decreased flow of the St. Clair, previously computed for the same period, was 30,600 cubic feet per second, which is 13,600 cubic feet per second in excess of the abstraction which the fall of Lake Erie accounts for. So that if there had been no change in the rainfall on Lake Erie during the two periods, the lake should be at the least calculation, about 4/10 of a foot lower than it is, were it not for the draft upon storage in Lake Huron-Michigan, which would reduce the lowering about .1 foot; or Lake Erie should be .3 of a foot lower than it was if there had been no change in precipitation.

Now, the precipitation on Lake Erie between the two periods shows that in the former it was 6 per cent. greater than it was in the latter; so that as Lake Erie is too high in the later period, we have the anomaly of a decrease of 6 per cent. in

the rainfall causing a rise in Erie of .3 of a foot, and a decrease of 4½ per cent. on Huron-Michigan, causing a lowering of 1.06 of a foot. So that it does not appear that the two results are consistent, and one or the other or both must be in error.

The level of Lake Ontario by Table 49, Exhibit XXXIV, has fallen from a mean of 246.52 for the period from 1860 to 1889 to a mean of 245.65 for the period commencing 1890 to 1907.

In 1903 there was constructed the so-called Gut Dam across one of the channels of the St. Lawrence, which raised the level of Lake Ontario, according to the complainant's witness Shenehon, file 6, page 43, being page 501 of the continuously paged record, about 5 inches for the period after 1903.

In answer to a question, after the witness had testified that he made certain prophecies based upon computations of the effect of the construction of this dam, the computations being based upon the discharge measurements of the St. Lawrence River, the question is:

"Q. Your computations were borne out, were they, by the actual observations?

A. It came within the limits stated. The actual rise of Lake Ontario, by reason of the Gut Dam, was about 5 inches."

This Gut Dam is indicated on Chart 3 of the St. Lawrence River, being Williams' Exhibit 18, and is shown extending from Galops Island to Adams Island, at the head of the channel marked "The Gut;" and is indicated by the legend "Gut Dam."

The width of the channel cut off is about 450 feet, according to scale on the map. This is located about 6 or 7 miles below Ogdensburg, which makes it about 67 miles below Lake Ontario. Apparently it cut off the flow through that channel entirely.

This dam was constructed by the Canadian Government in American waters, with the consent of the American Government, for the purpose of preventing a bad cross current in the Galops Rapids channel, which was used for navigation by boats going down the river, particularly; and this cross current striking the channel nearly at right angles, was liable to drive boats over against the farther side of the channel. It was constructed, according to the testimony, in 1903. A rise of 5 inches for three years of the 18 in the period, would raise the means 5/6 of an inch.

Q. You are speaking of the rise on account of the—

A. In Lake Ontario on account of the Gut Dam, which cov-

ers three years of this period, and if we distribute that over the whole 18, it becomes 3/18 times 12 times 5, I believe is the way it works out; it comes out about 5/6 of an inch, or .07 of a foot.

Q. The effect of the Gut Dam on the rise of Lake Ontario is still present, is it not?

A. Yes. So that if the Gut Dam had not been constructed, the mean elevation of Ontario during the later period, that is, from 1890 to 1907, would have been 245.65 minus 0.07 equals 245.58, showing a fall between the means of the two periods of 246.52 minus 245.58, or 0.94 feet, or slightly more than Erie. The diversions from Lake Ontario, effective during the later period only, are similar to those from Huron and amount to substantially the same quantity, or about 10,000 cubic feet per second, which, with an increment of 30,322 cubic feet per second, as derived from Table 42 when referred to changes of stage of Lake Ontario, would reduce the level of the lake about 0.33 foot. A further lowering of Lake Ontario of 0.94 minus 0.33 equals 0.61 foot is to be explained. This would represent a decrease of outflow of 0.61 multiplied by 30,322, or about 18,000 cubic feet per second. The decreased outflow of Huron, assuming it to have been due to deficiency of precipitation, as suggested by the complainant, must have been, as before stated, 32,900 cubic feet per second, which is, as in the case of Lake Erie, about 15,000 cubic feet per second more than the fall of Ontario accounts for, assuming no change in rainfall; the difference being 32,900 minus 18,000.

To this a correction should be applied for the contribution from storage on Michigan-Huron of approximately 3,170 cubic feet per second and a similar contribution from Lakes Erie and St. Clair of about 430 cubic feet per second, making a total of about 3,600 cubic feet per second, which would account for about 0.12 foot of this lowering. This reduces the amount unaccounted for to about 11,400 cubic feet per second. But the rainfall on the Ontario drainage appears to have been, from the figures already given, about 2.7 per cent. greater during the earlier period than during the later.

To summarize: on the complainant's theory that a reduction of rainfall accounts for the changes of lake levels—

Mr. Wilkerson: You mean on the statement of one of the complainant's witnesses.

A. Yes. On the statement of the complainant's witness that a reduction of rainfall—

Mr. Adcock: Is that the same witness you referred to—Haskell?

A. I refer to complainant's witness Haskell—that a reduction of rainfall accounts for the changes in position of the lake surfaces, we have a reduction of rainfall on the Michigan-Huron drainage of about 5 per cent., decreasing the discharge of the St. Clair River about 15 per cent., while a decrease of rainfall of about 6 per cent. on the Erie drainage increased the discharge of the Niagara River about 7 per cent.; and a decrease of rainfall of about 2.7 per cent. on the Ontario drainage increased the discharge of the St. Lawrence River about 6 per cent.

It therefore seems impossible, with the information which is available, to derive from the precipitation records satisfactory explanation of the changes in lake levels. And it is my conclusion that a considerable part of these changes is due to causes to be sought elsewhere.

An examination of Table XIX of Exhibit 34 shows that a reduction of the level of Huron-Michigan took place about 1889-90. For the six years preceding, 1884 to 1889, the mean elevation was 582.35; and for the six years following, 1890 to 1895, the mean elevation was 580.53, or 1.82 feet lower.

Lake St. Clair shows a drop at the same time from elevation 576.27 to 575.12, or 1.15 foot; and Lake Erie, a drop from elevation 573.04 to elevation 572.12, or 0.92 foot.

In the report of the Chief of Engineers for 1903, Appendix FFF, pages 2878, 2879, are given tables of precipitation on the several watersheds of the Great Lakes, which were identified by complainant's witness Wheeler.

Q. That was the mean annual precipitation?

A. Gives the monthly also. On the several watersheds of the Great Lakes, such tables being identified and testified to by the complainant's witness Wheeler in file 4, pages 92, 93, being pages 188 and 189 of the continuously paged record.

The mean annual rainfalls as shown in these tables for the periods last under consideration, namely, 1884 to 1889, and 1890 to 1895, were, for Lake Superior in the former period, 26.7 inches, in the latter period 25.60 inches, a decrease of 0.47 inches, or 1.8 per cent. On Michigan-Huron, for the former period an average precipitation of 32.07 inches, for the later period 31.91 inches, showing a difference of 0.16 inches, or 5/10 of 1 per cent. On St. Clair-Erie, for the former period, an average precipitation of 32.39 inches, for the latter period 34.94 inches, showing an increase of 2.55 inches, or 7.3 per cent. On Ontario, during the former period, an average pre-

cipitation of 34.83 inches, during the latter period 38.97 inches, showing an increase of the latter over the former of 4.14 inches, or 10.6 per cent.

From the Report of the International Waterways Commission, page 101, being the Report upon the Regulation of Lake Erie for 1910, to which reference has already been made, the flow of the St. Mary's River during the period from 1884 to 1889 is shown to have been at the rate of 78,616 cubic feet per second, and during the later period at the rate of 71,600 cubic feet per second, showing a decrease of 7,016 cubic feet per second between the two periods. And the surface of the lake, by Tables L of Exhibit 4 was at the same mean elevation for both periods.

The discharge, therefore, appears to have been reduced 9 per cent. by a decrease of rainfall of less than 2 per cent.

Complainant's witness Wheeler, in the report above, makes these discharges for the St. Mary's River, 70,388 cubic feet per second for the former period and 65,789 cubic feet per second for the later period, giving a difference of 4,590 cubic feet per second, discharge of the St. Mary's River, as computed by Mr. Wheeler and identified by him, as shown upon page 2,873 of Appendix FFF to the Report of the Chief Engineers for the year 1903.

The holding back of 7,016 cubic feet per second in Lake Superior would lower Lakes Michigan-Huron 7,016 divided by 28,872, equals 0.24 foot. So that on the theory of the complainant's witness Haskell, a reduction of 5/10 of 1 per cent. of the rainfall lowered these lakes 1.82 minus 0.24, equals 1.58 foot, equivalent to reducing the discharge 1.58 times 28,872, equals 45,600 cubic feet per second; and a rainfall of 0.16, which is the difference between the rainfall of the earlier and later period on Michigan-Huron, on the area of the land and water drainage of Michigan-Huron, would only amount to 1,624 cubic feet per second on a lowering of 0.056 of a foot, if we assume that all of this decreased rainfall would have reached the lake if it had not decreased, thus leaving 1.52 of a foot lowering, or a discharge of 44,000 cubic feet per second to be accounted for.

The rainfall of St. Clair and Erie shows an increase in the second period over the first, as does also that of Ontario; the former of 2.55 per cent., and the latter of 4.14 per cent.; yet Lake Erie lowered 0.92 of a foot between the two periods, and Lake Ontario lowered 0.53 of a foot.

From the foregoing it seems clear that some other cause

than reduced rainfall must be found to account for the changes of lake levels about 1889.

Mr. Wilkerson: I make the same motion with respect to this discussion on precipitation; with the same statement as to the furnishing of data, and as to the opportunity for cross-examination. And if I may be permitted, I would like to have this understanding, not only with reference to the testimony of this witness, but with reference to the witnesses who are to be examined in the future. It is obvious that the competency of a great deal of this hypothetical testimony, which is based upon assumptions of fact made by the witness, cannot be determined until the data from which the conclusions are drawn have been subjected to the test of the cross-examination of counsel; and I will reserve making any such motions at the time the evidence goes into the record, with the understanding that upon the conclusion of the Government's cross-examination of the witness, I will reduce these motions to strike the evidence, and such objections as go to the competency, materiality or relevancy of the evidence, to writing, and submit them to the counsel on the other side, and hand them to the Commissioner.

Mr. Austrian: And we will have an opportunity then, to supply and correct so far as we can, any testimony, to which the objection goes.

Mr. Wilkerson: Of course, you would have an opportunity for further examination of the witness after the objection is made.

Adjourned to Tuesday, March 25, 1913, 10 o'clock a. m.

March 25, 1913, 10 o'clock a. m.

Parties met pursuant to adjournment.

Present same as before.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Mr. Adcock: Referring to Table LIII, Mr. Williams, will you state how you have compiled that table and what it refers to?

A. Table LIII presents the cubic yards of material reported as removed from the channels of the St. Clair River, Lake St. Clair and the Detroit River from 1870 to 1910, the table being based upon the reports in the annual reports of

the Chief of Engineers covering the several localities that are indicated at the top of the table.

The first column gives the year in question; the second column covers the region at the lower end of Lake Huron, being the head of the St. Clair River, at which in the early days there was a bar upon which the depth of water appears to have averaged about 12 or 13 feet. The second column is headed "Mouth of Black River," and refers to the shoal which has been repeatedly dredged in front of the City of Port Huron; this shoal apparently reforming to a considerable extent after having been removed on altogether five different occasions.

Mr. Austrian: Are you referring to sheet 1?

A. I am referring to sheet 1 and sheet 2.

Q. Taken in connection with each other?

A. Taken in connection with each other.

Mr. Adcock: They are all a part of the same table?

A. All a part of the same table.

Mr. Austrian: What do the figures indicate?

A. The figures indicate the number of cubic yards of dredging reported as being done in these localities in the reports of the United States Engineer in charge of the work in the district, as published in the reports of the Chief of Engineers.

Mr. Adcock: And you refer to the specific portions of the reports, or any particular reports which make this up, if there is any dispute about it.

Mr. Wilkerson: This I understand is a compilation made from the Government's reports?

A. This is a compilation made from the Government reports.

Q. And you have a memorandum indicating what—

A. It indicates the year. I have the memoranda giving the information in detail. It is all compiled from the report of the engineer in charge of the Detroit office; begins with the reports, I believe, of General Poe. It is the report of the Detroit office, all the time.

Q. This, I understand you to say, shows the total quantity moved, without showing the disposition?

A. This shows the total quantity moved or reported moved from the channel.

Mr. Adcock: At the particular points indicated?

A. At the particular points indicated, or in the particular localities indicated.

The third column, which is headed "St. Clair River," cov-

ers those portions of the St. Clair River below the Black River shoal and above the St. Clair Flats Canal.

The fifth column headed "St. Clair Flats Canal," covers the excavation in connection with the improvement of the St. Clair Flats Canal; that is, at the foot of the St. Clair River.

The sixth column headed "Grosse Point Cut," refers to that channel which was dredged in the nineties across the lower end of Lake St. Clair, cutting away the bar at the head of the Detroit River, which prior to that time had restricted navigation—or given a restricted depth of about 16 feet at low water.

The next column, that is, the seventh, gives the total amount of material removed from the St. Clair River and Lake St. Clair.

The eighth column gives the amount of material removed from Ballard's Reef, so-called, which is the upper obstruction in the Detroit River, and is situated a short distance above Amherstburg, on the Canadian shore.

The ninth column gives the excavation reported for the Lime Kiln Crossing, which is a short distance below Ballard's Reef; and from the reports, it is evident that at times the work on the Lime Kiln Crossing included work on Ballard's Reef, and *vice versa*, so that these two improvements are to be considered as practically one and the same thing, except that there is not a duplication in the figures.

The tenth column, which is marked "Outlet," indicates the material removed from the Detroit River below the Lime Kiln Crossing in the shoals, mainly of earthy material, which existed at the mouth of the Detroit River, or at the head of Lake Erie. The excavations at Lime Kiln and Ballard's Reef were to a considerable extent in rock.

The eleventh column is headed "Livingstone Channel," and gives the excavations as reported from the Livingstone Channel for the years 1908, 1909 and 1910. This channel was completed in 1912, but the figures have not been extended to cover that date, as they were not accessible to us at the time this table was prepared.

The next to the last column gives the total excavation in the Detroit River from Ballard's Reef to the outlet inclusive, and the last column of the table gives the grand total of all excavations reported for the St. Clair and Detroit Rivers in the years in question. At the bottom of the table—

Q. When you say, "St. Clair and Detroit," that includes Lake St. Clair, doesn't it?

A. And Lake St. Clair, yes. At the bottom of the table,

the first page, are given the totals of each column for the periods from 1870 to 1892, inclusive; and at the bottom of the second sheet are given the totals for the periods from 1893 to 1910, from 1870 to 1892 and for the entire table from 1870 to 1910 inclusive.

There is also at the lower right-hand corner of the table a statement of the total amount of material removed from the channels from 1903 to 1910, which is 14,975,331 cubic yards, out of a total for the entire period of 25,290,830 cubic yards.

Q. What other investigations have you made with reference to channel improvements of the St. Clair and Detroit Rivers and Lake St. Clair?

A. I made, in the late nineties, an examination of the effects of the channel improvements in the St. Clair River upon the water supply of Detroit, and had occasion at that time to examine very carefully the original records of the dredging inspectors in the United States Engineer's office at Detroit, through the courtesy of the chief officer in charge; and also to refresh my personal recollections of a considerable portion of this work which was carried on under my observations, to the extent that I could see it going on during my connection with the Detroit Water Works. And it was my recollection of the large amount of work that was done at this time that first directed my attention to that as a possible explanation of the change in lake levels which occurred about 1889 and 1890, as shown by the tables which have been put in evidence heretofore.

This led to a more careful investigation of the relations between the excavations in the channel—I will say of the apparent relations between the excavations in the channels and the changes in lake levels, which has been made by a study of the reports of the Chief of Engineers upon the subject, by conversations with engineers and others who were associated with the work, and by reference to personal memoranda which had been taken from time to time, bearing upon the subject, in the course of my professional work independent of this case.

Mr. Wilkerson: All the work in these channels, about which you are speaking now, was work done by the Government under the authority of the War Department?

A. Yes, sir. There is nothing included in LIII which has not been done by the authority of the War Department under the direction of the engineer officer in charge of the district.

There has been in certain localities considerable further excavation for commercial purposes, particularly recently in

the vicinity of Port Huron, at the head of the St. Clair River, where, within a few years, the removal of material for building purposes (that is, for the sand and for the gravel) was stopped, as a result of the influence brought to bear by the United States Engineer Office upon the Canadian authorities, as I am informed.

Mr. Wilkerson: That is, it was work that was being done by Canadians?

A. It was work being done by Canadians, which it was conceived would interfere with—possibly increasing the outlet of Lake Huron, and interfering to that extent with navigation.

Q. The War Department protested, with the result that the work was stopped?

A. The protest was lodged, and as a result the work was stopped. I do not know whether it went clear through the official channels, or was arranged locally. It is all a matter of record; it could be looked up.

Mr. Adcock: Will you state what conclusions you have reached, and the basis of such conclusions, giving the facts which you have considered in connection with such channel improvements, as to their effect upon the lake levels?

A. The first important work done towards improving navigation in the waters connecting Lakes Huron and Erie was the creation of a 12-foot channel through the St. Clair River, which was completed about 1858, by the construction of the St. Clair Flats Canal. Prior to this, the limiting depths in the latter river, which was at the Flats, was about 9 feet. My impression is that was the mean.

Q. That is prior to what time?

A. Prior to 1858. It is difficult to discover any effect of this improvement upon the level of Lake Huron, for the reason that there are on record no accurate or reliable elevations of the lake for this period, by which it can be compared with the elevations of other lakes for the period prior to this improvement. There are some elevations about this time, but they do not extend back far enough to give a sufficient average to warrant a statement as to the actual effect of these improvements.

The St. Clair Flats Canal, at which these improvements were made, is shown on Williams' Exhibit 7 entitled "Chart of the St. Clair River, including foot of Lake Huron and St. Clair Flats Canal," in the lower left-hand corner of the chart; and the original channel, which was improved in 1858, is represented by the legend, "St. Clair Flats Canal," and extends

between the two upper lighthouses indicated as "St. Clair Flats Canal, Upper Light," and "St. Clair Flats, Lower Light;" the lighthouses being indicated by red dots in a yellow field.

It will be noted that beyond the portion of the channel which is marked "St. Clair Flats Canal," there is an extended dredged area reaching out into Lake St. Clair, indicated by the white through the blue, and the excavations from this channel have been included in the column marked "St. Clair Flats Canal," in Table LIII just described.

Between 1867 and 1871, the St. Clair Flats Canal was deepened to 13 feet, and progressively until 1874, to 16 feet. At the same time, the Lime Kiln, at the mouth of the Detroit River, was similarly deepened. The location of the Lime Kiln is shown upon Williams' Exhibit 9, being a chart of the Detroit River; being located approximately opposite and just above Ft. Malden, which is about a mile above the town of Amherstburg; and is substantially opposite the coffer dam represented attached to Stony Island in the lower half, or lower quarter of the chart.

This early improvement of the Lime Kiln consisted largely in the removal of loose boulders, and did not involve the removal of any large quantity of material. These improvements were followed, in 1874 to 1879, by the removal of the bar at the mouth of Black River at Port Huron, which is shown on Williams' Exhibit 7, "Chart of the St. Clair River, etc.," the bar being indicated by the blue coloring opposite the lower end of the City of Port Huron, at the upper end of the St. Clair River and near the top of the chart. The Black River is seen emptying into the St. Clair, cutting the City of Port Huron into two parts. The purpose of this improvement was to produce a navigable depth along the city frontage of 15 feet.

After the completion of this work, the famous Lime Kiln Channel enlargement was begun, in 1876, and continued until its final completion in 1891. This enlargement was in the locality indicated previously on the chart of the Detroit River, and contemplated a depth of water of 20 feet at the average stage.

In 1888 the Lime Kiln Channel had been completed to a width of 300 feet throughout its length, giving a depth of about 20 feet of water; and in 1889 a width of 350 feet could be depended upon.

Mr. Austrian: You say "throughout its length;" have you given its length?

A. I have not. The improvement covers about, altogether, that improvement which extended not only through the Lime Kiln, but up through Ballard's Reef, covers about four miles of river, the aim being to dig out the shallow spots. There were deep spots in that length, where no improvement was necessary.

During the same year, and the year following, 1889 and 1890, a large amount of material was again removed from the bar at the mouth of Black River; a depth of over 16 feet being secured, and a consequent enlargement of the carrying capacity of that portion of the St. Clair River being produced.

The effect of the improvements between 1876 and 1891 does not appear in its completeness until about 1890, although the changes in lake levels coincident with it are indicated, as shown in Table XIX by the decrease in fall between Lake Huron and Lake Erie, as far back as 1887.

In 1893, four, five and six, very extensive channel improvements were made at the foot of the St. Clair River, and through Lake St. Clair, by the dredging of a 20-foot channel through the bar at the foot of Lake Huron. The location of this dredging is shown on Exhibit 7, "Chart of the St. Clair River" at the top of the chart; the dredging taking place right at the head of the St. Clair River, and extending up some three or four miles into the lake. That channel, if my memory serves me correctly, was 2,500 feet wide, and the bottom was cleaned off to a depth of 20 feet.

The amount of material excavated at this point, as shown in Table LIII during the years 1893 to 1897, was nearly one million cubic yards.

In 1893, work on the Grosse Point Channel was commenced, and extended to the end of May, 1897. Grosse Point Channel is located at the head of Detroit River, at the foot of Lake St. Clair; and is shown on Williams' Exhibit 8, "Chart of Lake St. Clair," the lower left-hand corner of the chart. It extends from the deep, or white water indicated in Lake St. Clair, to the head of the Detroit River, a distance of between two and three miles. From this locality, over five and a half million cubic yards of material was reported to have been handled during the period of this improvement, giving a 20-foot depth entirely across Lake St. Clair.

Mr. Austrian: When you say "reported," you mean what?

A. Reported in the reports by the Engineer Officers, or reported by the Engineer Officer, to have been removed. In 1908, work began on the Livingstone Channel, through the

Lime Kiln, and in 1908, 1909 and 1910 nearly 9,000,000 cubic yards of material are reported by the Engineer Officer to have been removed; and about 400,000 cubic yards more were removed along the old channel, in this vicinity.

The Livingstone Channel is shown upon Williams' Exhibit 9, "Chart of the Detroit River," the upper end of it being enclosed in the coffer dam attached to Stony Island just above the town of Amhertsburg on the Canadian shore, all of which is in the lower left-hand quarter of the sheet.

During the construction of the Livingstone Channel, the upper end of it was enclosed in a coffer dam, that the excavation through the rock might be made in the dry. And the first effect of this improvement was to reduce the discharging section of the Detroit River, raising the water above the coffer dam, and ultimately in Lake St. Clair to a small extent. This channel was completed in 1912 and the coffer dam removed, so that water was free to flow through the excavation in the rock underneath the coffer dam as made in August, 1912, since which time it has added to the discharging capacity of the river as it existed prior to the opening of the coffer dam.

The change in conditions at the head of the St. Clair River is shown by a comparison of plates 7 and 8 of Exhibit 34, of which plate 7 is a photograph of a portion of the chart of the St. Clair River, secured from the United States Lake Survey Office in 1897, by me, which is stamped with the legend, "Aids to Navigation corrected from information received to April 20, 1892." To this photograph have been added in ink two parallel lines enclosing the bar opposite Fort Gratiot; and there has been added in ink "Datum 582.489," being the elevation to which the soundings are referred, when corrected for the revised levels of 1903. The soundings on this chart—

Mr. Adcock: What do you mean by "Revised levels of 1903?"

A. The revised levels of 1903 is a term used to designate the correct elevations of bench marks along the lakes, as a result of precise level determinations, which were made between 1900 and 1903, connecting the benches in this section of the Great Lakes with the benches which had been previously connected to tidewater. It was found as a result of these levels, which were very carefully run, that there were small errors in the old elevations of the benches, in some of them the errors being greater and some less. And in the report of the Chief of Engineers for 1904, Appendix EEE, page 4070, are given the elevations in Table I of bench marks by

what is designated as the old and new levels. The old levels are now referred to ordinarily as 1877 levels, being based upon the determiantions made by the Lake Survey in 1877; and the new levels are referred to as the 1903 levels, being based upon the determinations made by the Lake Survey in 1903.

It will be noticed that the changes which are shown in the third column of the table are comparatively small. The largest change in this table appears at the U. S. bench mark E at Harbor Beach, which, according to the new levels, is 0.507 feet higher than it was according to the old levels.

I would say that all the elevations of lakes given in the exhibits so far introduced have been those referred to the 1903 levels, but it is necessary to keep that fact in mind, because in connection with some of the records, or in connection with all of the records published prior to 1903, the reference is to the 1877 levels, and the elevations would be in error by the amount of the correction which is indicated in this table, for the particular locality.

Since 1903 there has been an additional correction of 6/100 of a foot, or .06, affecting the levels of Lake St. Clair; and this correction has been taken into account in the elevations presented in the exhibits so far in this case. That will be detected by a difference in the elevations of Lake St. Clair, as presented in the report of the International Waterways Commission on the Regulation of Lake Erie for 1910, and the elevations for Lake St. Clair as presented in the blue print exhibits in this case, so that by the levels of 1903, as readjusted, I think in 1910, the level of Lake St. Clair has been found to be .06 higher than was indicated prior to that time, and as shown in the reports of the International Waterways Commission.

Plate 8 is a photograph of a portion of the chart of the same river, being Williams' Exhibit 7, "Chart of the St. Clair River," upon which two parallel ink lines have been drawn, as near as I was able to draw them in the same position as those on plate 7, and the datum elevation has been entered in ink as 578.50, which is taken from the legend on Exhibit 7.

On Plate 7 the soundings marked in the area between the two ink lines enclosing Fort Gratiot Light, omitting only the eight fathoms which is just above the bar on the left-hand side, and which by comparison with the latter chart appears to be an error, as it is hard to conceive how there could have been eight fathoms of water there in 1877, and only 24 feet

plus the change of datum in 1910, for that reason I have omitted that eight fathoms from the computation. Taking the average depth of the other soundings indicated between those two lines on the chart, based on the surveys of 1877 and purporting to be corrected to 1892, the average depth through this area is 22.1 feet below the datum of 582.49, or an average bottom elevation of 560.4 feet above sea level.

Plate 8 is from a chart of the same river, stamped: "Issued May 10, 1911," and at the bottom in the center bears the legend, "Aids to Navigation, corrected from information received to May 10, 1911, March 23rd, 1912, August 24, 1912."

On this latter plate, photographed from the chart purporting to represent the conditions of the channel at the head of the St. Clair River, the soundings in the area enclosed between the similar parallel lines show an average depth of 28.4 feet below the datum elevation of 578.50, or the average bottom elevation of 550.1 feet. Comparing this with the average bottom elevation shown on the photograph of the former chart, Plate 7, it indicates a difference of average bottom elevation through this section of 560.4 minus 550.1, or 10.3 feet. In other words, it is apparent by the comparison of these charts, that the channel through the bar at the foot of Lake Huron, which must have been to a very large extent the controlling factor in the outflow of Lake Huron, has been deepened 10 feet for its average width from shore to shore, between the times covered by the information contained in these two charts.

Since the conclusion of the discharge measurements of 1902, there has been removed from the waters connecting Lakes Huron and Erie, about 15,000,000 cubic yards of material. If this excavation were concentrated in a continuous stretch of 20 miles, 20 miles covering the entire distance over which such improvements have been made, it would make a channel 600 feet wide and 6¼ feet deep.

The effect of this work has been, according to the report of the Chief of Engineers for 1911, page 3013, to increase the discharge of the St. Clair River for the same stage by about 3 per cent. And 3 per cent. of the discharge of the St. Clair River, as indicated by the measurements from 1889 to 1902 would be about 5,700 cubic feet per second.

Mr. Wilkerson: You spoke of averaging these figures on Plates 7 and 8?

A. Yes.

Q. You mean to say that you averaged the figures just as they appeared on those plates?

A. Just as they appeared.

Q. As they are photographed here?

A. Yes.

Q. And giving equal weight to each figure?

A. Equal weight to each figure. There was no attempt to reduce at all.

Q. And you took the figures as they appeared on Plate 7, and the figures as they appeared on Plate 8?

A. Yes. Now, comparing the information on Table LIII with Table XIX of Exhibit 34, which shows the mean annual elevations of the Great Lakes, and the difference in elevations, it is noticed at once that the very marked fall which occurred in Lake Huron with reference to Lake Erie, about 1889, was coincident with the completion of the Lime Kiln Channel at the foot of the Detroit River, which removed what had been, up to that time, an effective weir, controlling to a very large extent the discharge of the Detroit River. This bar was cut through during the previous years, the channel being gradually widened until, as stated, in 1888 it was 300 feet wide. By that time, the increased discharge of the Detroit River had lowered Lake St. Clair and produced an increased flow through the St. Clair River, which in turn lowered Lake Huron, and the effect upon Lake Huran became apparent suddenly about 1889 or 1890. The lowering of Lake Huron is seen, by Table XIX, to continue through the following ten years, being coincident with the large excavations across Lake St. Clair, at the head of the St. Clair River, and further excavations in the Detroit River. The comparisons of these two tables offers to my mind a clear explanation, and a sufficiently complete one, of the changes in the lake levels which occurred about 1889, and which has been heretofore attributed to changes in precipitation and evaporation.

The mean elevation of Lake Huron from 1860 to 1889 was 581.91; the mean elevation from 1890 to 1912 has been 580.43, or 1.48 feet lower.

The mean elevation of Lake Huron from 1884 to 1889 inclusive, was 582.35; and the mean elevation from 1890 to 1895, inclusive, was 580.53, or 1.82 feet lower. In other words, between those two six-year periods—and I take six years in order that I may eliminate any influence of deficient precipitation in a single year; ice, or anything that might make the reference to a single year misleading—the difference of elevation between these two six-year periods has been 1.82 feet. No such sudden drop in the level of Lake Huron is observable anywhere else in its history, so far as our data of elevations

go, and it must have been caused by some particular and special cause, some unnatural cause, as no natural cause can be conceived, which would produce such a remarkable change as this one. That unnatural cause is found in the evidence of Table LIII, in the excavation of material from the Lime Kiln Crossing at the foot of Detroit River, which, prior to its excavation, had controlled the discharge of the river. When this channel was cut through, it enabled the water to flow away more freely, the discharge of the River was increased; the result was a lowering of Lake St. Clair, which increased the fall from Huron to St. Clair, thereby increasing the flow of the St. Clair River and decreasing the level of Lake Huron, as indicated in the actual observations of elevations.

It is possible to determine approximately the amount by which the discharge of the St. Clair River has been increased between its mean discharging capacity for the period from 1860 to 1889, and the period from 1890 to the present time. This may be determined by reference to Table XXI of Exhibit 34, which shows that the fluctuations of Erie, with reference to Huron, during the period from 1860 to 1889 were 75.3 per cent.; and during the period from 1891 to 1910 85.5 per cent., during the latter period. As there has been no marked change, so far as we know, in the discharging capacity of the outlet of Lake Erie during this period, it follows—

Mr. Adcock: During which period?

A. During any of the period from 1860 to 1910. It follows that the conditions of fluctuation, as related to increment, must have been practically constant for Lake Erie during this time; and therefore, it affords a saisfactory standard of comparison for the fluctuation of Huron during the two periods. This fluctuation, as presented in Table XXI, is based upon the mean annual change of elevation of the two lakes.

Then the fluctuations of Huron in the later period as compared to those in the earlier period will be as 75.3 divided by 85.5, or as 0.88; or the fluctuation in the later period will be 0.88 of the fluctuation in the earlier period.

Q. That is the fluctuation in Huron?

A. Of Huron.

Q. That is, the two periods being from—

A. The two periods being, the first from 1860 to 1889, and the second from 1891 to 1910.

This being the same reservoir involved, there are no modifying influences to affect the general rule that the fluctuation is inversely as the increment, and therefore the increment

of the St. Clair River during the earlier period must have been about seven-eighths per cent. of the increment during the later period.

Q. That is, the smaller the increment, the greater the fluctuation?

A. The greater the fluctuation.

Q. The greater the increment, the smaller would be the fluctuation?

A. The smaller will be the fluctuation, because in order to discharge a given quantity of water with a small increment, the lake must rise higher in order to get that water out; and conversely to discharge a given quantity of water with a large increment, it is not necessary for the lake surface to rise so high.

Now, by the principle already enunciated, that when a change is made in an open channel, which increases the increment, the discharge will be changed in a greater proportion than the increment is changed, it follows that the discharging capacity during the period from 1860 to 1889 must have been at the greatest not to exceed 87½ per cent. of that for the period from 1891 to 1910.

Q. You mean the discharge or the discharging capacity of the channel?

A. The discharging capacity. The average discharge of the St. Clair River, from 1900 to 1907, has been computed by the defendant's equation, as shown on Table XL, to be 197,633 cubic feet per second, and it therefore follows that for the same stages as existed between 1900 and 1907, under the conditions of channel existing from 1860 to 1889, the discharge of the river must have been less than 87½ per cent. of 197,633, or less than 172,500 cubic feet per second.

It therefore follows that the changes which have been made in the channels of the St. Clair and Detroit Rivers, beginning with the work upon the Lime Kiln Channel, which was completed in 1891, have had the effect of increasing the discharging capacity of the St. Clair and Detroit Rivers for an average stage, as represented by that existing from 1900 to 1907, by not less than 25,000 cubic feet per second, which is equivalent to an ultimate lowering of these lakes, of not less than 10.4 inches, using the increment derived by the defendant for the conditions of the later period as shown in Table XXXIII.

Q. Have you computed the increment for the previous period?

A. The increment for the previous period would be 87½

per cent. of that for the later period, or about 25,300 cubic feet per second.

Q. What would have been the lowering by this increased discharge, according to the increment deduced for the earlier period?

A. Approximately one foot. It has already been pointed out in my testimony that the effect of the storage in Lake Superior and the diversion through the Chicago Drainage Canal would account for a lowering of Lake Michigan-Huron of about .37 of a foot, and by the changes in the channel, we have accounted for a lowering of nearly 9/10 of a foot, which leaves about 3/10 of a foot to be explained by conditions not definitely determinable, as rainfall and evaporation effects, and other climatological influences.

Direct examination of witness adjourned.

Recess until 2 o'clock p. m.

Depositions in the above entitled cause, taken pursuant to stipulation of counsel for the respective parties, before the Commissioner, statutory notice being duly waived, at the Plaza, New York City, commencing July 17, 1913.

Appearances: Mr. James H. Wilkerson, representing the Government. Mr. Edmund D. Adcock and Mr. Alfred S. Austrian, representing the Sanitary District.

All objections to questions, answers and exhibits shall be considered as having been made, except as to questions involving form and secondary evidence.

GARDNER S. WILLIAMS resumed the stand for further direct examination by Mr. Adcock, and testified as follows:

Q. I think in your previous examination, you stated that the discharge of the Detroit River was measured in the year 1901. Have you made any examination of the discharge measurements of that river, as shown by the records in the Lake Survey office?

A. I have made an examination of the published reports of the discharge measurements of the Detroit River, as they are presented in the Report of the Chief of Engineers for 1903, Appendix FFF, pages 2816-17.

There is also some further information in regard to these

measurements in the report for the year 1902, page 2867; but the 1903 report is the summarization of all the work.

Q. Will you state what investigations and examinations you made, and the conclusions that you have reached?

A. These discharges were examined with a view to ascertaining whether they would support the conclusions drawn from the other observations, whether by any chance they might corroborate the Niagara discharges, or whether they would corroborate the St. Clair and St. Lawrence discharges, or whether they might be inconsistent with all of them.

As previously stated, the discharge of the Detroit River was measured at Ft. Wayne, just below the City of Detroit, by Mr. Murray Blanchard, under the direction of Professor E. E. Haskell, a witness for the complainant in this case, between June and December, 1901, and between June and November, 1902, all inclusive. The results are published, as previously stated, and the discharges are there referred to gauge readings at Windmill Point, on Lake St. Clair, which is a short distance above the head of the Detroit River, and at Ft. Wayne, the gauging section, and at Amherstburg, at the foot of the Detroit River which is really a short distance upstream from the mouth. As published, the gage heights are in terms of the so-called "1877 levels" and when transferred to the "1903 levels," the mean results are:

	Windmill Pt.	Ft. Wayne	Amherstburg	Discharge
1901	574.84	573.99	571.55	201,237 cfs
1902	575.12	574.39	572.71	196,871 cfs
1901–2	574.99	574.20	572.34	198,960 cfs

In explanation I might say that the results for 1901-2 are not the averages of the figures given above, but are the means of all the observations during the entire period; the number of observations being different in the two years. The discharge of the Detroit River is influenced, not only by the elevation of Lake St. Clair, but also by that of Lake Erie, so that an increment cannot be derived by the simple processes used for the Niagara and St. Lawrence Rivers, but must involve a procedure similar to that adopted for the St. Clair.

The number of observations involved on the Detroit does not permit so thorough an investigation as that made on the St. Clair, but by grouping the observations with first one lake constant and then the other, the increment due to Lake St. Clair alone appears to be 45,380 cubic feet per second; and that due to Erie alone, 17,290 cubic feet per second.

From Table XXI of Exhibit 34, it has been shown that Lake Erie's annual fluctuations are 0.855 of those of Huron,

while those of Lake St. Clair are 0.894 of Huron, whence the fluctuations of Erie are the ratio of these two, or 0.956 of those of Lake St. Clair.

The average net increment of the Detroit River from 1890 to 1910 would therefore be 45,380 minus .956 times 17,290, which equals 28,850 cubic feet per second, or substantially the value previously determined for the St. Clair.

The reason for saying that this covers the period from 1890 to 1910 is that we accept these observations made in 1901 and 1902 as representing an average of the conditions of the Detroit River from 1890 to 1910 except as the lake was affected by the work at the Livingstone Channel.

It is to be recalled that the similar process of computing an increment, when applied to the St. Clair gave a value about nine per cent. less than that finally obtained by a more precise determination, and a similar discrepancy may be expected in the case of the Detroit, so that an increment for the latter of about 32,000 cubic feet per second is to be predicted from the preceding result.

The number and range of the Detroit observations are not sufficient to permit of such a treatment as that finally adopted in the case of the St. Clair, but the observations on the Detroit River may be divided into five groups, including altogether 93 out of a total of 117 observations.

Q. What is the treatment you refer to there, with reference to the St. Clair?

A. The treatment of grouping is at times when the stage of the lakes were uniform, or that is, were reasonably constant. There are not enough points to be derived to get a satisfactory equation.

Q. Do you remember what tables those were referred to?

A. Yes. As set forth in Tables XXVIII and XXXIV.

Q. Of Exhibit 34?

A. Of Exhibit 34. I was able to get 93 out of 117 and thereby form five groups, which covered periods as follows:

July 19 to August 3, inclusive, 1901, 11 observations.

August 15 to September 7, inclusive, 1901, 25 observations.

October 7 to October 21, inclusive, 1901, 11 observations.

July 1 to August 2, inclusive, 1902, 26 observations.

October 14 to November 4, inclusive, 1902, 20 observations.

Mr. Wilkerson: Have you a statement there of the ones which you did not consider?

A. No; they can be identified in the table. The reason for leaving out any was, there was either a break in the time of observation, so that they were isolated observations, or

there was a marked change in the conditions as indicated by the change in discharge, so that what I was endeavoring to get here was a group of observations that represented reasonably constant conditions on the two lakes.

Q. I was just inquiring as a matter of convenience so that we would know if you have any tabulation formed of the ones not considered.

A. No, I have not. They are in the report, and you can refer to them.

Having the gage elevations at Windmill Point and Amherstburg, and the discharge for those five groups, it seemed that it should be possible to derive an increment for the Detroit River from these five equations. The method of least squares was applied, and most absurd results were obtained, or absurd results were obtained; the net increment being about 16,000 cubic feet per second, which is on the face of it impossible, since the Detroit increment must be greater than that of the St. Clair, and nobody as yet has conceived a method to bring the increment of the latter to a value less than 16,000. This indicates that the relations between the variables in the equations are not sufficiently established to permit the derivation of an increment from them, although the discharges may be measured with a reasonable degree of precision. The average of the discharges measured for the five periods is 200,880 cubic feet per second. The average discharge of the St. Clair River for the same periods determined by taking the average lake elevations at Harbor Beach and St. Clair Flats for the entire time covered by the five observation periods, and applying the defendant's equation is 201,500 cubic feet per second, or within 620 cubic feet per second of the average of the Detroit measurements.

During the time included in the selected periods, Lake St. Clair as shown by the gage at Windwill Point, comparing its elevation on the first and last days of each group rose .39 of a foot. Since Lake St. Clair has an area of 503 square miles, a rise of one foot in one day would be equivalent to a storage of 162,300 cubic feet per second, and a rise of .39 in the 140 days covered by the selected periods would, therefore, represent a storage of 450 cubic feet per second, so that in the preceding comparison the computed discharge of the St. Clair River for the entire length of the five periods exceeds the average of the observed discharges of the Detroit River plus the storage in Lake St. Clair by 170 cubic feet per second.

During the period from June to November, inclusive, the

average run-off per square mile for the Lake Erie-St. Clair watersheds is 0.252 cubic feet per second, as shown in Table LXIXa of Williams' Exhibit 34. The area of the land watershed tributary to Lake St. Clair and the St. Clair below the Dry Dock Section is 5,691 square miles, by the report of the International Waterways Commission, whence there is to be expected an increase of discharge of the Detroit River over the St. Clair River of about 1,430 cubic feet per second. This quantity is reduced by the water abstracted by the Detroit Water Works that is used for the generation of steam and for lawn and street sprinkling, which does not find its way into the sewers. During 1901 and 1902, from an examination of the records of the pumping at the Detroit Water Works, this is estimated at about 15,000,000 gallons daily during the period of the gagings, which is about 230 cubic feet per second. The net result is that the Detroit River discharge should have been about 1,000 cubic feet per second greater than that of the St. Clair for the periods in question. The gagings of the Detroit River, therefore, disagree with those of the St. Clair by about 1,200 cubic feet per second, which is less than 0.6 of 1 per cent. The gagings of the St. Clair being reduced by the defendant's equations.

The Detroit measurements then afford a further check upon the accuracy of the St. Clair and St. Lawrence observations, and a further proof of the incorrectness of the Niagara results. As already shown in Table XXI of Exhibit 34, the annual fluctuations of Lake St. Clair are 89.4 per cent. of those of Lake Huron, and as the water contributed by the Lake St. Clair drainage is relatively insignificant, the increment of the Detroit must be 1 divided by 0.894, or 1.12 times that of the St. Clair.

As previously shown, the St. Clair increment is about 28,872 cubic feet per second, and that of the Detroit then is is about 32,300 cubic feet per second, or slightly more than the value of 32,000 previously predicted from the investigation of separate increments.

We, then, have the following equation referring back to the fact that the fluctuation of Erie is 0.956 that of St. Clair; S minus 32,300 plus 0.956 E equals Zero; that is the algebraic sum of the increments due to Lake St. Clair designated as S and Lake Erie designated as E must equal the net increment of the Detroit River; in which equation S is the increment due to Lake St. Clair and E that due to Lake Erie.

By a comparison of the monthly changes in mean eleva-

tion of Lake St. Clair and Erie for months when Lake Huron was at the same mean elevation as presented in Table LV, these observations being taken for the open season only as the presence of ice entirely nullifies the value of any such comparison, a rise of one foot in Lake Erie is accompanied by an average rise of .49 in Lake St. Clair.

A rise of 0.49 foot in Lake St. Clair will reduce the flow of the St. Clair River by 0.49 times 13,000, equals 6,370 cubic feet per second, since the increment of the St. Clair River due to the changes of Lake St. Clair is minus 13,000, as previously derived by the defendant and substantially the same figure being arrived at by the complainant, and since the inflow from the land areas to Lake St. Clair is not appreciably changed, the discharge of the Detroit River must be correspondingly reduced, whence it follows that 0.49 S plus 6,370 plus E must equal Zero, where S is as before the increment of the Detroit River due to changes in Lake St. Clair and E the increment due to changes in Lake Erie.

Solving these two equations for the values of S and E, we find that S equals 72,200 cubic feet per second, and E equals minus 41,750 cubic feet per second, or a rise of one foot in Lake St. Clair would increase the discharge of the Detroit River by 72,200 cubic feet per second, and the rise of one foot in Lake Erie would reduce the discharge of the Detroit River by 41,750 cubic feet per second.

At first sight, having in mind the increments of Huron and St. Clair for the St. Clair River, one is inclined to doubt the correctness of these values, but an examination of the characteristics of the two rivers makes it evident that with its shorter length, greater cross section and less slope, any change in either lake will produce a very much greater effect in the Detroit than in the St. Clair. This is also established by the fact that if, under average conditions, Lake Erie were suddenly to rise 2.61 feet, it would be at the same level as Lake St. Clair at Windmill Point and the flow of the Detroit River would be reduced to zero. It then follows that for this extreme variation the average increment of Lake Erie would be about 200,000 divided by minus 2.61, equals minus 76,500 cubic feet per second. On account of a steeper slope between Mamijuda Light and Lake Erie, this being the lower quarter of the river, the increment for the changes near the normal stage of Erie would be less than for those as the level of Lake St. Clair was approached.

Similarly if under ordinary conditions, by reason of ice jams in the St. Clair River and its local tributaries, the in-

flow to Lake St. Clair should be cut off and the lake should fall 2.61 feet at Windmill Point, it would be at the same level as Lake Erie, and the flow of the Detroit River would be again reduced to zero, in which case the average increment of Lake St. Clair would be 76,500.

As a combination of these conditions led to a reversal of flow of the Detroit River in February, 1896, there is nothing forced in these assumptions, and no reason appears for doubting the correctness of the increment of 72,200 cubic feet for Lake St. Clair and 41,750 cubic feet per second for Lake Erie above derived for average conditions.

Referring again to the results of the comparisons of discharges with Lake Erie constant and then with Lake St. Clair constant, if there be excluded from the former, those cases would show a decrease of discharge for a rise of St. Clair and an increase of discharge for a rise of Erie, both of which conditions are inconsistent with the laws of nature, the separate increment would be 81,300 for St. Clair and minus 38,720 for Erie. In other words, the two methods of derivation of an increment, even though the number of observations to be used is too limited to render the results certain, agree within certainly a fair range for observations of this kind.

For the purpose of some further comparisons, the discharge of the Detroit River will be computed for the average open season elevations from 1900 to 1907, inclusive, which will be designated as the reference condition. The purpose of using this period from 1900 to 1907, inclusive, is that it is the period most closely comparable with the conditions at the time of the gagings in 1901 and 1902, as since 1907 the presence of obstructions in connection with the Livingstone Channel, and later the opening of the channel itself, have caused a change of conditions in the river, which has made the flow to follow somewhat different laws since 1907 than it followed from 1900 to that date. During this period from 1900 to 1907, as shown by Williams' Exhibit 27, the mean elevation at Windmill Point was 575.13, and at Amherstburg, 572.65. The mean elevations during the gagings of the Detroit River were: Windmill Point, 574.99 and at Amherstburg 572.34.

During the month of July, 1902, there were 23 discharge measurements made at Ft. Wayne extending from the 1st to the 31st inclusive, no two being made the same day, and giving a mean of 204,506 cubic feet per second. These measurements must therefore represent fairly the average discharge of the Detroit River during that month.

The mean elevation at Harbor Beach for July, 1902, was

580.76, and the mean at St. Clair Flats was 575.76. The discharge of the St. Clair River of July, 1902, was by the defendant's equation 201,013 cubic feet per second. To this should be added the inflow from the Lake St. Clair drainage, which for the month of July has an average value of .3 cubic feet per second per square mile, and for 5.691 square miles would amount to 1,707 cubic feet per second.

The Detroit Water Works was abstracting about 230 cubic feet per second, as previously computed, and the rainfall exceeded the evaporation based on the Rochester Observations of evaporation, which are presented in table LXII of Williams' Exhibit 34, by about .25 of a foot. This is equivalent to a flow of 1,309 cubic feet. During the month, Lake St. Clair rose .27 of a foot, which represents a storage of 1,414 cubic feet per second. The expected discharge of the Detroit River would then be the discharge of the St. Clair as above quoted, 201,013 cubic feet per second, run-off from St. Clair drainage 1,707 cubic feet per second; excess of rain over evaporation on the lake surface, 1,309 cubic feet per second or 204,029 cubic feet per second less storage of 1,414 cubic feet per second and the use of water by the Detroit Water Works of 230 cubic feet per second, that being the water which does not reach the sewers, amounting to a total subtractive quantity of 1,614 cubic feet per second, leaving a net discharge for the Detroit River of 202,415 cubic feet per second. The measured discharge was 204,506 cubic feet per second, showing an excess of 2,091 cubic feet per second, or about 1 per cent. of the measured discharge. This may be almost wholly, if not wholly accounted for by the excess run-off over the average from the St. Clair drainage, as the rainfall for July, 1902, at Detroit was 4.19 inches, or more than 100 per cent. in excess of the normal which would be expected to increase the discharge or the inflow to Lake St. Clair by something in the neighborhood of 2,000 cubic feet per second.

This again shows a close agreement between the Detroit and St. Clair discharges when reasonably interpreted, and we may therefore use the conditions of July, 1902, to establish the reference discharge of the Detroit River for the period 1900 to 1907 inclusive. The elevation at Windmill Point for the reference period was .37 of a foot lower than it was during July, 1902. The elevation at Amherstburg was .66 of a foot lower than it was in July, 1902. The observed discharge of 204,506 cubic feet per second should then be reduced for the decreased height of Windmill Point by 0.37

times 72,200 or 26,700 cubic feet per second, and should be increased on account of low stage of Erie by .66 times 41,750, or by 27,555 cubic feet per second, making a net positive correction of approximately 800 cubic feet per second. The reference discharge then is 204,506 plus 800 equals in round numbers 205,300 cubic feet per second.

The mean dscharge of the St. Clair for the reference period by the defendant's equation is, as already stated, 197,163 cubic feet per second, and allowing 2,000 cubic feet per second as the net increase of discharge between the Dry Dock Section of the St. Clair and the Ft. Wayne Section of the Detroit, the difference between the two determinations of the reference discharge, the one based on the Detroit measurements directly and the other on the St. Clair observations, is 6,100 cubic feet per second, or about 3 per cent. of the average of the two determinations.

Q. By reference discharge there, you mean for a certain period?

A. That is the reference, I said I would call that period from 1900 to 1907 the reference period.

As the St. Clair discharge is based on the larger number of observations, it is entitled to the greater weight, and it is therefore concluded that the reference discharge of the Detroit River is about 199,000 cubic feet per second.

In the month of August, 1912, there was completed through the reefs at the foot of the Detroit River a new channel, 300 feet wide, having a navigable depth of 22 feet, where in places there were formerly only about four feet of water. In the construction of this channel, a considerable portion of the river was closed by a coffer dam from early in 1908 until the completion, and the material from the excavation was spoiled in the shoaler water on both sides of the work. Prior to the beginning of the work, no discharge measurements were ever attempted in that portion of the Detroit River, so far as it has been possible for me to learn. But during the construction, and since completion, several discharge measurements have been made.

The effect of the cofferdam prior to the completion of the work was to raise the level of the river above it, and also both Lake St. Clair and Lake Huron, as shown in table LXIII of Williams Exhibit 34, the slope from St. Clair to Erie being increased about 0.10 foot by the backwater raising the former, and Lake Huron would in time be raised about one-fourth as much. On the opening of the channel, the river very soon assumed its usual slope, and it becomes of interest

to ascertain whether the discharge under normal conditions of slope and stage will be greater or less than before the work commenced.

The river in the locality in question, as shown by Williams Exhibit 9, is divided by Grosse Isle into two channels. The Western or Trenton Channel being unaffected by the improvements except as they affect the slope between its two extremities, and the velocity and depth of the approaching water. Discharge measurements made in this channel on August 29th and 30th and December 5, 1912, after the opening of the Livingstone Channel, when reduced to the conditions corresponding to a normal determination by the mean stages of Lake St. Clair and Erie for the open season from 1900 to 1907, that is to our reference discharge as shown on charts 1, 2, and 3 of Williams Exhibit 34, gives a discharge of 35,818 cubic feet per second.

Mr. Wilkerson: Are those observations published?

A. They are published; I have blue prints here. Part of them are published and part are in the form of blue prints, which I got from the Government Office.

To the east of Grosse Isle as shown on Williams Exhibit 9 and to a larger scale on Williams Exhibit 10, entitled "Lower Detroit River," the river is divided again by a small island known as Stony Island, and the channel between it and Grosse Isle is designated as "Stony Island Channel." The discharge of this channel was measured on August 20 and 21 under conditions closely approximating the normal above adopted, that is the reference condition, and when these discharges are reduced to the reference condition as shown on chart 4 of Exhibit 34, the discharge becomes 11,203 cubic feet per second. The Livingstone Channel cofferdam extended eastward from Stony Island as shown on Williams Exhibit 10 to the so-called Lime Kiln or Amherstburg Channel, and the new cut opens through the middle of it, that is through the middle of the cofferdam. A discharge measurement was made on this channel December 17, 1912, when the conditions were not far from the reference conditions, when reduced to those conditions as shown on chart 5 gave a discharge of 37,400 cubic feet per second. Measurements made on the Lime Kiln Channel October 24, and December 18, 1912, when reduced to the reference conditions as shown on chart 6 give an average discharge of 106,098 cubic feet per second.

Combining the discharge of the several channels reduced to the condition of the river from 1900 to 1907, as indicated

by the mean stages of Lake St. Clair and Erie, we have: Trenton Channel, 35,818 cubic feet per second; Stony Island Channel, 11,203 cubic feet per second; Livingstone Channel, 37,400 cubic feet per second; Lime Kiln Channel, 106,098, making a total of 190,519 cubic feet per second.

The International Waterways Commission in the report on the regulation of Lake Erie for 1910, at page 102 give the discharge of the Detroit River for the several years from 1900 to 1907 from which the average is found to be 189,900 cubic feet per second. This result is out of harmony with that which is obtained from the Detroit gagings when the relation that the velocity varies as the square root of the hydraulic radius times the slope is applied to the whole series of the Detroit River gagings. Applying this well known relation, we have the mean fall from St. Clair flats to Lake Erie during the gagings was 575.36 minus 572.12 equals 3.24 feet. The mean elevation at Ft. Wayne was 574.20, or .2 of a foot below elevation 574.40 at which the area of the section is given in the report of the Chief of Engineers for 1903, page 2814, as 76,770 square feet; and from the cross section of the river at Ft. Wayne which is published in the report for 1902, opposite page 2870, the width appears to be about 2235 feet, although it is not marked.

The area of the section during the reference period then would be approximately 76,770 minus 0.2 times 2,235 or 76,-323 square feet. The hydraulic radius was approximately 76,323 divided by 2,235 or 34.15. The mean velocity was 198,960 divided by 76,323 or 2.60 feet per second. The mean elevation of the Ft. Wayne gage for the open seasons of 1906 and 1907 was 574.596; that of St. Clair Flats was 575.675, and that of Lake Erie 572.635. The fall from St. Clair Flats to Ft. Wayne was 1.08 and to Erie 3.04. The fall to the former was therefore 35.5 per cent. of the latter. The mean elevations of St. Clair Flats and Lake Erie for the open seasons from 1900 to 1907 were 575.43 and 572.41 respectively, showing a fall of 3.02 feet. The fall to Ft. Wayne from St. Clair Flats would therefore be 0.355 times 3.02 equals 1.06 feet for the reference period, and the elevation at Ft. Wayne would be 575.43 minus 1.06 equals 574.37 or 0.03 less than 574.40 at which the area as above stated is given as 76,770 square feet. This reduces the area of the section by 0.03 times 2,235 equals 67 square feet or to 76,703 square feet. The hydraulic radius would be approximately 76,703 divided by 2,235 equals 34.32. The discharge for reference conditions then would be 76,703

times 2.60, times the square root of 34.32 divided by 34.15 times the square root of 3.02 divided by 3.04, which equals one finally, as it happens, the influence of the hydraulic radius almost cancelling the influence of the change in slope, so that our final result is 76,703 times 2.60 which equals 199,428 cubic feet per second, or substantially the same value obtained for the reference discharge by reference to the St. Clair discharge. This incidentally affords further evidence of the consistency of the St. Lawrence, St. Clair and Detroit measurements and the inconsistency of those at Niagara. It therefore appears that the net result of the Livingstone Channel work has been to decrease the discharge of that section of the Detroit River about 8,500 cubic feet per second, that is the difference between 199,000 cubic feet per second, the reference discharge for the period from 1900 to 1907, and 190,500 cubic feet per second, the discharge obtained by the summation of the separate discharges measured after the opening of the Livingstone Channel, which may be expected to ultimately raise Lake St. Clair about 1.4 inches, and Lake Huron about one-fourth as much. An increase in the width of the Livingstone Channel is contemplated from 300 feet as at present to 450 feet, and the excavation through the rock section included in the cofferdam has already been extended to the greater width. When the entire channel is increased to its width, this width, for the same stages of water above and below, the discharge will be increased by about 50 per cent.; or at normal stages by nearly 20,000 cubic feet per second, and if this be uncompensated it may be expected to lower Lake St. Clair something over three inches, or somewhere about three inches, and Lake Huron by an amount corresponding to a diversion of about 3,000 cubic feet per second at Chicago.

Q. That is according to the deductions from the discharge measurements?

A. Deductions from the measurements made by the complainants.

I will now call attention to table LXIII of Exhibit 34 entitled "The effect of the Livingstone Channel." The first column represents the year upon which the information is based. The comparisons have been made with October, November and December only, for the reason that the Livingstone Channel was opened in September, and no observations covering the other months were available to us at the time this table was prepared; so that we were forced to make the compari-

son with the last three months in the year. And it will be noticed that in 1909, the December elevations have been omitted. That is for the reason that during December, 1909, there was an ice gorge in the Detroit River which caused conditions to be entirely unnatural and therefore we were forced to reject December, 1909, and base the average for that year on the two months of October and November.

The fifth column gives the mean elevation for the months of October, November and December for each year. The sixth column gives the fall from Lake Huron to Lake St. Clair. Columns 2, 3 and 4 give the elevations of Lake Huron at Harbor Beach. Column 5 gives the mean elevation. Column six gives the fall from Harbor Beach to St. Clair Flats. Columns seven, eight and nine give the elevation of St. Clair Flats for October, November and December. Column ten gives the mean elevation. Column 11 gives the fall from St. Clair Flats to Erie, and columns 12, 13 and 14 give the elevation of Lake Erie for October, November and December.

Column 16 gives the mean elevation of Lake Erie for the three months, and the last column gives the fall from Huron to Erie.

It will be seen that during the period 1900 to 1907, the mean elevation of Lake Huron was 580.63; the fall from Huron to St. Clair was 5.41 feet; the mean elevation of St. Clair Flats was 575.22. The fall from St. Clair to Erie was 3.28 feet. The mean elevation of Erie was 571.94 and the fall from Huron to Erie was 8.69, so that the fall from Huron to St. Clair was 62.2 per cent. and the fall from St. Clair to Erie was 37.8 per cent. of the fall from Huron to Erie.

For the conditions from 1908 to 1911 inclusive, or during the construction of the Livingstone Channel, the average fall from Huron to St. Clair was 59.2 per cent. and from St. Clair to Erie was 40.5 per cent. of the fall from Huron to Erie. For the three months of 1912 after the opening of the Livingstone Channel, the fall from Huron to St. Clair was 61.2 per cent., or within one per cent. of what it was during the period from 1900 to 1907, and the fall from St. Clair to Erie was 38.8, or again within one per cent. of what it was during the previous period, and the elevations were as indicated in the line opposite 1912.

A summary of the results is presented at the bottom of the table headed "Changes in feet" whence it appears that from the conditions of 1900 to 1907 and the conditions of 1908 to 1911 Huron fell 0.62, St. Clair fell 0.21 and Erie fell 0.34.

The slope from Huron to St. Clair was reduced 0.41; from St. Clair to Erie the slope was increased 0.13 and from Huron to Erie the slope was decreased 0.28.

Comparing 1908 to 1911 with 1912, the elevation of Huron increased 0.41, St. Clair increased 0.18 and Erie increased 0.27.

The fall from Huron to St. Clair was increased 0.23; from St. Clair to Erie was decreased 0.09 and the fall from Huron to Erie was increased 0.14.

Comparing the period 1900 to 1907 with 1912, we find that the elevation of Lake Huron was decreased 0.21, St. Clair was decreased 0.03 and Erie 0.07. The fall from Huron to St. Clair was decreased 0.18, from St. Clair to Erie was increased 0.04, and the fall from Huron to Erie was decreased C.14.

To interpret the indication from this table, it is that the opening of the Livingstone Channel restored very nearly the conditions which existed prior to the obstruction of the river during its construction; the slopes in the two rivers, the St. Clair and the Detroit, being returned to within one per cent. of the relations which they occupied to the whole slope prior to these constructions.

Q. Since the date of the taking of the testimony at the last hearing, have you prepared any further tables to be added to Exhibit 34?

A. Yes.

Q. Will you state what they are?

A. As a result of inquiries which were made at the previous hearing, certain tables have been added for the information of the complainant, and also other tables to be used in connection with the testimony just given and to follow have been appended; and by agreement they are incorporated as a part of Williams Exhibit 34, and will now be identified.

The first table that has been introduced is table XVIII a, which is a table showing the elevations of Lakes Huron, St. Clair and Erie and the falls between the several lakes for the closed season, December to March inclusive, from 1861 to 1912. The arrangement of this table is similar to that of table XVIII, which gives similar data for the open season, and to table XIX, which gives similar data for the full year. They are based upon the records furnished by the United States Lake Survey and presented as Williams Exhibit 26.

The next table that has been introduced is table XLV a, consisting of five sheets, and shows the preliminary computa-

tions for the discharge of the Niagara River referred to the Buffalo gage, which were summarized in table XLV previously. This table has been introduced at the request of the complainant, and a copy of it previously furnished.

The next table in question that has been added is table XLVI a, which is a recomputation of the increment of the Niagara River when referred to the mean elevation of the Buffalo and Amherstburg gages. It was found that in the computations of table XLVI, the method of weighting the observations was slightly different from that which had been used in the other computations; that is instead of distributing each gaging over the period covering half the elapsed time between the preceding and following gaging, they had been simply taken as the average of the days in question; and in order that the tables might be on the same basis, although we lay no particular stress upon them, we recomputed and have added this table XLVI a, which shows what the increment based upon the Buffalo and Amherstburg mean daily records would be, if those observations were treated in exactly the same way that the Buffalo observations are treated in table XLV.

It will be noticed that the change in the increment due to this change in the method of weighting is inconsiderable.

The next table, table XLVI b, is an increment for the Niagara River derived by reference to the Amherstburg gage, being treated in the same manner as the Buffalo gage in table XLV, and the Buffalo and Amherstburg in table XLVI a.

This is interesting as showing an increment for Lake Erie when referred to the Amherstburg gage of 47,217 cubic feet per second.

The next table that has been introduced is table XLVII a, which bears the same relation to table XLVII that table XLVI a bears to table XLVI. That is it was found that in computing table XLVII, the observations had been simply averaged for the period covered, instead of distributed with reference to the time elapsing between them and table XLVII a then represents the increment computed in a manner entirely analogous to that computed for the Buffalo gage in table XLV. The increment as obtained here is 33,590 as compared with 32,060 in the previous one.

Q. That is the Niagara River?

A. That is the increment for the Niagara River referred to the Cleveland gage; and by this computation, which is analagous to that used for the Buffalo gage is 33,590, whereas

by the other method of weighting the individual observations, it is 32,060.

Table XLVIII-a gives the annual precipitation at various stations on the Great Lakes, and comprises three sheets. This table was previously summarized in table XLVIII, but the entire data is presented for such reference as may be desired.

Table LV is the next table, and that follows table LIV and shows the relative fluctuations of Lake St. Clair and Erie during the open season, April to November inclusive; these fluctuations being based upon the changes of elevations with Lake Huron at constant or practically constant elevations.

In other words it was to establish the relation between St. Clair and Erie independent of changes of Lake Huron; and results in the relation that the change of Lake St. Clair when Lake Huron remains at a constant elevation is 49 per cent. of the change of Lake Erie.

Table LVI gives winter temperatures, that is the closed season from December to March inclusive, at Detroit, Buffalo and Oswego for the period from 1889 to 1912.

Table LVII is a table of drainage areas of the Great Lakes and is based upon the report of the International Waterways Commission. The first column gives the names of the rivers. The second column of this table gives the total drainage area tributary to the river in question in both land and lake.

The third column gives the total area of lake surface in the drainage, and the fourth column gives the total land area. The fifth column gives the local land and lake area; that is that of the particular river in question, or between that river and the one next following. The sixth column gives the local lake area. The seventh column gives the local land area.

The last column in the table gives the amount in cubic feet per second which would be represented by a run-off of one inch per year on the local lake surfaces.

Table LVIII gives a comparison of the river discharges; the first column giving the names of the rivers; the second and third column giving the discharges; the second column being the total discharge of the river and the third column being the discharge of the river less the discharge of the river next upstream; in other words being the local discharge.

This information is here given as derived by the complainant's equation for the period from 1900 to 1907, as presented in the report of E. S. Wheeler for 1882 to 1898, in the report of the Chief of Engineers for 1903, and as reported by the

International Waterways Commission, in their report on the regulation of Lake Erie for 1910, covering the period from 1890 to 1904, that is winter and summer.

The fifth and sixth columns give the run-off per square mile, the fifth being the total land and lake surfaces and the sixth column the total land surfaces.

The seventh and eighth columns give the local run-offs per square mile; the seventh column being for land and lake surfaces; the eighth column for land surfaces alone.

The last column represents the run-off per square mile in cubic feet per second of the streams that have been gaged upon the several watersheds.

Table LXIX-a gives a summary of the observations of run-off from the several drainage basins of the Great Lakes for each month in the year covering the basins of Huron, Michigan, Erie, St. Clair and Ontario; also for the full year for the open season April to November inclusive, and for the period June to November inclusive.

From this table it appears that the average run-off per square mile for the full year from the Huron-Michigan drainage area is 0.866 cubic feet per second; for the St. Clair-Erie drainage area 0.664 cubic feet per second, and for the Ontario drainage area 1.440. For the open season period from April to November inclusive, for the Huron-Michigan drainage, the average run-off is 0.844; for Erie 0.415; for Ontario 1.339. For the June to November period inclusive, the average run-off from the Huron-Michigan area is 0.640; for the St. Clair area 0.252, and for the Ontario area 0.924.

Table LXIX-B presents in detail the run-off from the Huron-Michigan drainage areas by months, and represents the method of computing the run-off as summarized in the preceding table. This method was to take the total discharges that were observed in each month and divide by the total areas which were represented by those discharges so that the average all the time is the average discharge of the entire area on which observations were available.

Table LXIX-c gives the similar information for the Lake Michigan drainage alone, and shows the rivers upon which the gagings were taken and the years over which the gagings extended, and also the months in the years which the gagings actually covered. This is composed of 14 sheets.

Table LXIX-d gives similarly the run-off from the Lake Huron drainage; and is composed of five sheets.

Table LXIX-e gives similarly the run-off from the Lake Erie drainage, and is composed of seven sheets.

Table LXIX-f gives the similar information, the run-off from the Lake Ontario drainage, and is composed of 11 sheets.

Table LX-a, composed of two sheets, gives the summary of the rainfall upon the drainage areas of Huron-Michigan, Erie and Ontario respectively from 1900 to 1904, by months and also for the full year, the April to November period and the June to November period.

Table LX-b, composed of five sheets, gives in detail the precipitation on Lakes Huron and Michigan for the period from 1900 to 1904 inclusive.

Table LX-c, composed of 3 sheets, gives similar information as to precipitation on the Lake Erie drainage area.

Table LX-d, of three sheets, gives similar information for the Lake Ontario drainage area. These tables have been compiled from the published records of the United States Weather Bureau.

Table LXI-a gives the summary of the mean temperatures observed by various observers on the Great Lakes. The two sources of information are the reports of the City Water Works at Chicago and Milwaukee on Lake Michigan, and Detroit on Lake St. Clair, at Cleveland on Lake Erie and at Toronto on Lake Ontario; and also the records of the United States Lake Survey give temperatures taken at various light houses and light ships on the several lakes and cover Lake Michigan, Lake Huron, Lake St. Clair, Lake Erie and Lake Ontario. This table is composed of two sheets.

Table LXI-b, embracing five sheets, gives in detail the temperatures of lake water and of air at the several water works, pumping stations just referred to; being those at Chicago, Milwaukee, Detroit, Cleveland and Toronto.

Table LXI-c gives the information obtained from the United States Lake Survey of temperature observations of air and water at various light house and light ship stations on the Great Lakes; it embraces six sheets.

Table LXI-d gives surface water temperatures observed by representatives of the United States Lake Survey from boats in passing through Lakes Superior, Michigan, Huron, the St. Clair River, Lake St. Clair, Detroit River and Lake Erie, and covers five sheets.

Table LXII gives the meteorological records at Rochester as published in the annual report of the Board of Public Works of Rochester for 1907, which is the last report that has been printed. It shows records of evaporation from a tub floating in the Mt. Hope reservoir, and also from a tub above

the water, mounted on a raft about 30 inches above the water's surface.

The table presents in its first column the years in question; in the second column the month. The third column gives the evaporation from the exposed tub, being the one mounted about 30 inches above the water's surface of the reservoir. The fourth column, the evaporation in inches from the tub floating in the reservoir and filled with water substantially to the level of the water outside it.

The fifth column gives the temperature of the water in the exposed tub in degrees Fahrenheit. And the sixth column gives the temperature of water in the floating tub, in degrees Fahrenheit.

The seventh column gives the temperature of the water in the reservoir at the same time in degrees Fahrenheit and the eighth column gives the temperature of air in the shade, in the vicinity of the tub. And the last column gives the precipitation in inches observed at the Mt. Hope reservoir.

In the lower half of the table is given the records at the United States Weather Bureau's station at Rochester; the first column representing the years; the second column the month; the third column the precipitation in inches; the fourth column the normal precipitation or the mean precipitation for that month since 1870. The fifth column, the mean temperature for the month in question. The sixth column, the normal temperature for that month, or the mean since 1890. The seventh column, the mean humidity during the month in question, and the last column the normal humidity or the average since 1870.

This table is of interest in connection with estimates of the evaporation from the lake surfaces, and constitutes the most extensive observations upon the evaporation from water surfaces that have been made anywhere in the world, so far as an extended investigation of the authorities on the subject reveal.

Table LXIII has already been described, being the table referring to the effect of the Livingstone Channel.

Table LXIV shows a comparison of results obtained with the Haskell meter at the Hydraulic Laboratory of Cornell University, when the rating was made by moving the meter at a regular speed through the water, and when a rating was made by moving the same meter under similar conditions at irregular speeds through the water.

This table will be discussed further.

Q. By whom were those observations made?

A. The observations were made by myself.

Q. Table LXV shows the average elevation of Lakes Michigan, Huron, St. Clair and Erie for each of ten years, and for the ten years preceding the opening of the Chicago Drainage Canal; and also the average elevation of the same lakes for each of the ten years immediately succeeding the opening of the Drainage Canal; and the mean for the period of ten years.

Q. One for the period immediately preceding, and one immediately following?

A. And the one for the period immediately following.

Chart 1 shows the computations involved in the reductions of the observations of discharge of the Detroit River in the vicinity of the Livingstone Channel, to reduce them to the reference condition of average lake elevations 1900 to 1907.

Q. Charts 1, 2 and 3 refer particularly to the Trenton Channel?

Q. Those are charts. We did not have charts before?

A. No, we did not have charts before. Chart 4 refers to the Stony Island Channel; chart 5 to the Livingstone Channel, chart 6 to the Lime Kiln Channel.

Plate 9 has been added, which shows the cross sections of the St. Clair River, the Niagara River, Bridge Section, Niagara River Open Section, St. Lawrence River and the Sanitary District Canal, all drawn to the same scale; the relations between the horizontal and vertical sections being natural.

The scale is: One inch equals 250 feet; the cross sections for the several rivers being taken from the reports of the Chief of Engineers of the United States army, as presented in connection with the gagings of the several rivers. The section of the Drainage Canal is the rock section, which has the largest carrying capacity of any portion of the channel.

Plate 10 is a profile of the St. Clair and Detroit Rivers and Lake St. Clair, being based upon the profile published in the report of the United States Deep Waterways Commission, and corrected for the recent deepening of channels and changes in water surface. The solid areas, first at the foot of Lake Huron, then at the head and foot of Lake St. Clair and finally at the foot of the Detroit River, represent the material that has been removed and the increased depth of channel that has taken place in those localities as a result of the Government's improvements of navigation. That is the solid white as distinguished from the cross hatching representing

the bottom of the stream. This is of course distorted; the scale being as indicated in miles at the bottom, and as indicated in feet along the left hand side of the plate; but it is an exact copy except for cutting deeper to the present depth of channel.

Recess to 2:30 p. m.

After recess, 2:30 p. m.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Mr. Adcock: Now you have those tables before you?

A. Yes, sir.

Q. Ready to substitute them?

A. To substitute these in place of Exhibit 34.

Mr. Adcock: I submit to the Commissioner a number of sheets and offer them in evidence as Williams Exhibit 35, consisting of 18 sheets, designated as charts 1, 2, 3, 4 and 5; chart 1 consisting of five sheets; chart 2, one sheet; chart 3, consisting of four sheets; chart 4, six sheets, and chart 5, two sheets.

(Whereupon the charts so submitted to the Commissioner were marked Williams Exhibit 35.)

Q. Mr. Williams, will you describe the exhibit that has just been identified?

A. This exhibit consists of five charts numbered from 1 to 5. Chart 1 consists of five sheets and is a plotting of the gage elevations of Lake Huron at Harbor Beach, and Lake St. Clair at St. Clair Flats, covering the periods during which gagings were in progress on the St. Clair River and somewhat antecedent thereto. There is indicated on these charts in numbers the discharge found on the respective days when gagings took place. There is further indicated by arrows on this chart the periods which were included in the preparation of table 28 of Williams Exhibit 34. This chart 1 represents the gagings of 1899 to 1902 inclusive.

Chart 2 gives similar information for the gagings of the St. Clair River for 1908, 1909 to 1910 inclusive, and the periods indicated by the arrows and the Roman numerals correspond to those in table 34 of Williams Exhibit 34.

Chart 3, consisting of four sheets, gives similar information as to the elevation of Lake Erie at Cleveland during the

gagings, and the periods represented are those of table XLVII.

Chart 4, consisting of six sheets, gives similar information as to the elevation of Lake Erie at Buffalo, and the periods are those indicated in table XLV-a of Williams Exhibit 34.

Chart 5, comprising two sheets, represents the similar information for the St. Lawrence gagings, gage heights both at Ogdensburg and Oswego being plotted. The periods are those used in table XLI of Exhibit 34.

These plottings show, of course, the daily indicated fluctuations of the lake levels during the periods covered by them, and are noticeable as indicating that during the earlier gagings of the St. Clair, Lake St. Clair was apparently at a uniform elevation in some cases for as much as three weeks, which is, of course, a physical impossibility, as the elevation of the lake changes from day to day. The only reasonable inference to draw is that the gage reader did not read the gage, but simple put down from day to day the same reading that the gage had at some time when he did read it; and, of course, the resultant inaccuracies of gage reading must be reflected in any deductions of discharge, in which those gage readings play a part. If the readings of Lake St. Clair for the period of June, 1899, for instance, be compared with those of June and July, 1910, shown on Chart 2, sheet 6, the impossibility of the condition appearing in chart 1 must be evident.

Q. From the examination which you have made and the facts and data which you have heretofore presented in evidence, and your investigations of the discharge measurements of the various rivers under consideration, the St. Clair, the Detroit, Niagara and St. Lawrence Rivers, and the relative sizes of the drainage areas, will you state what conclusions if any you have reached with reference to the accuracy or possible inaccuracy of the discharge measurements of those rivers made by the Lake Survey?

A. In beginning to answer this question, I would like to repeat what I said earlier in my testimony, that so far as the work done by the Lake Survey parties in the field, so far as the possibility of accomplishment with the means at their hands is concerned, I think that they did a most remarkably creditable piece of work.

The criticisms which I have to make upon it are criticisms that to a large extent are at present beyond the power of man to remedy.

The gagings of the St. Lawrence, Detroit and St. Clair Rivers when considered with the variations of the elevations of the lake surfaces show a remarkable agreement, and indicate that whatever errors exist in the observations are of similar magnitude in all. As to the absolute accuracy of any of the measurements, there is no means of determination except the consistency of the observations themselves; and they all might easily be in error as much as ten per cent. On account of the size of the rivers involved, there is no possibility of making a comparison of this method of measurement with any other method of measurement.

Q. You are referring to the methods used and described heretofore?

A. Yes, in making a comparison of the methods of measurement used by the Lake Survey with any other method of measurement. So the accuracy of the observations are dependent: First, upon the accuracy of the reading of the meters; second, upon the consistency with which the meters retain their rating during the periods of observation. Third, upon the extent to which the position observed in the cross sections of the stream are representative of the flow in other parts of the stream. Fourth, as to whether the index velocities are always in the same ratio to the vertical and horizontal curves which they are supposed to represent.

And, fifth, as to whether it is possible to connect the discharge of any of these rivers at any particular time with any particular elevation of the Lake Surface.

The fact that at all of these gaging stations the discharge was actually affected, with possibly a single exception, by the elevation of a body of water below as well as above the gaging station, whose elevation, though dependent in a measure upon that of the water above, does not fluctuate with it according to a continuous law, and owing to the fact that any influence must travel from one lake to another before its full effect can be measured at any point between, all these make the possibility of accurate measurements extremely doubtful.

In a considerable experience with current meters and comparisons of their discharge with that of weirs, it has never been possible to get the two to agree within less than about 2 per cent., and differences of 10 to 20 per cent. have not been infrequent. I am speaking now of my own experience.

A long series of comparisons were made at the Hydraulic Laboratory of Cornell University by the New York State Barge Canal Survey, and are reported in the "Barge Canal

Report'' of the New York State Engineer for 1901, pages 932 to 951.

In these experiments, the current meters usually underregistered about 3 per cent., the situation being one where the conditions were extremely favorable for accurate meter work, in that the channel was rectangular, and it was possible to determine the area of the cross section with great accuracy and also to locate the position of the meter.

The meters were handled from rigid rods and were not allowed to drift upon lines or be dependent upon weights to maintain them in position. Moreover, the water was sufficiently clear so that the observer could see the position of the meter and visually observe whether it was operating in a rational manner or not.

In the rating of a pair of current meters for the Lake Superior Power Company in 1900, the effect of moving the meter through the water at speeds varying from point to point was investigated to determine the influence of the pulsations ordinarily felt in the lower parts of all large streams.

The meter was suspended on a rod from a truck which ran upon tracks spanning the canal.

The canal at the laboratory is 16 feet wide between side walls which are vertical and approximately 10 feet deep and about 30 feet in length.

The truck was built of wood and was propelled by hand at that time, as they had not yet installed the electric apparatus for driving the truck. A crew of men was employed to push the truck along the track, and the distance was taken by trips, forming an electric contact, at 10 feet intervals along the rail, and communicated by a chronograph to a sheet of paper.

The revolutions of the meter were similarly taken by the chronograph and the time was taken from a chronometer, all records being taken electrically, so that there was no step with which human agency was involved in getting the record of revolutions, velocity and time.

In the regular readings of the meter, the car was propelled at as nearly a uniform rate as was possible throughout the full length of the course, and the ratio between the revolutions of the meter and the velocity of propulsion recorded. Later it was suggested it would be interesting to ascertain what would be the effect on the meter if instead of being propelled at a uniform rate, the car would be propelled at an intermittent rate; that is to say, if a car were given a shove and then allowed to slacken its speed as the result of friction, and then

given another shove so as to give it a jerky or pulsating motion.

This method of rating was then carried out, so far as it was possible to do so with the apparatus. You will see at once that as high speeds were reached, it was impossible to give very many pulsations in going over the course, as the men could not accelerate the car to a velocity much beyond its average velocity.

The result of these observations are presented in table LXIV. In the left hand side of the table are the observations at a regular velocity. I may say that the observations presented in these tables were made with a Haskell Current Meter, which was owned by the Michigan-Lake Superior Power Company. It was similar in every respect to those which were being used by the United States Lake Survey at the same time. These observations were made in, I think, 1899.

Q. Were they made by you personally?

A. They were made by me. I was assisted in these observations by Mr. J. A. Vogleson, who is now the chief of the Bureau of Health of Philadelphia. He had at that time just been graduated from Cornell University, and was going to the Soo to assist in discharge measurements which the Lake Superior Power Company contemplated making on the St. Marys River at that time.

The first column of the table gives the group of observations.

The second column gives the number as they appear in the note books, each observation being numbered.

The third column gives the revolutions observed during each observation and the fourth column gives the velocity. The fifth column gives the ratio of the velocity to the revolutions.

In the right hand half of the table is presented similar information for the ratings at the irregular speeds.

Column 6, again, gives the number of the observations as found in the note book; column 7, the revolutions observed; colnmn 8, the observed velocity, and column 9, the ratio of the velocity to the revolutions.

It will be observed in comparing columns 5 and 9, that while at a velocity of about two feet a second the ratio of velocity to revolutions is practically the same for both the regular and irregular rating, that as the speed increases the number of revolutions corresponding—or rather the velocity corresponding to a given number of revolutions, increases in the case of the irregular rating over the similar ratio for the regular rating. So that at a velocity in the neighborhood of three feet

per second, the meter was under registering about 4 per cent. on the regular rating.

When the velocity had gotten up to between 3½ and 3⅝, the meter was under registering about 6 per cent. Beyond that it was, as I said, impossible to maintain the irregularity of speed to the same degree as was obtained at the lower velocities, so that by the time a velocity of four feet was reached, the under registration amounted to only about 3 per cent., and by the time a velocity of six feet was reached, the variable or irregular impulses practically integrated into a regular impulse, and the ratio comes back to the same figure.

These experiments showed that when moved through the water at irregular speeds, if the instrument be free to turn about both its axes, the Haskell Meter will under-register as much as 6 per cent. and very probably more at higher velocities.

These observations afford an explanation of the disagreement of the Niagara gagings with the others, as at the Niagara the current is much more disturbed and irregular than at any of the other stations. Eddies and whorles are constantly appearing at the surface, and so pronounced that they can be seen in crossing the International Bridge on the cars, and if this turmoil appears at the surface, we perhaps can imagine to some extent what it must be down in the depths of the river, where the agitation starts.

The condition is very well expressed in the language of Mr. F. C. Shenehon, in his report upon the gaging of the Niagara, in the report of the Chief of Engineers for 1900, page 5342, where he says:

"In such a section as that at the International Bridge, the proper derivation of the velocity co-efficient is the most difficult part of the river gaging. To obtain it, the writhing mass of waters streaming through the bridge openings and eddying about the piers, spurting and lagging in minor pulsations, speeding faster as the lake rises and flowing leisurely in low stages must be congealed to a solid by some instantaneous method of survey, and its dimensions taken."

It is not difficult to conceive of one of these eddies catching the tail of the meter and whirling it around at right angles to the direction of the main current.

Q. Will you describe the Haskell Meter somewhat in detail, so that we can get some idea of how it operates in the water?

A. The Haskell Meter consists of a shaft upon one end of which, the front end, is a wheel shaped similar to a propeller

wheel, so that the current as it comes towards the meter striking the blades of this propeller causes it to revolve. As it revolves, a contact is made and broken with an electrical recording or sounding apparatus, so that each revolution is transmitted to the recording device in the hands of the observer.

At the other end of this shaft, there is a vane or tail, which keeps the meter pointed upstream, or is intended to keep it pointed upstream, and in a reasonably straight current does so.

The meter is supported a short distance back of the propeller, and is allowed to vibrate, or to rotate both in the horizontal plane and in the vertical plane so that it may assume a position parallel to the direction of flow whichever way that may come.

The length of the ordinary Haskell meter from tip to tip is about 30 inches. I am speaking from memory, and I have not measured one in a long while. The direction meter is about 3½ feet long. I should say it was between 30 and 36 inches.

The point that I have in mind in connection with these eddies is that it is entirely possible that the head of that meter might be in a current that was moving fairly straight, while the tail of it was caught by an eddy and whirled around so that the wheel no longer pointed against the current, but might be in an angle away from parallelism with the directions of flow; and if it does not point in the direction of flow then its revolutions will be less for the same current than they would be if it pointed directly towards the oncoming current.

Q. I take it the Haskell meter is not unlike the weather vane that we sometimes see built by boys, a toy with a wheel revolving at right angles to the plane?

A. The same principle is involved, exactly. Of course, the Haskell meter is a more delicate instrument and more strongly built, being designed to resist the flow of moving water. And I may say that it is an exceptionally creditable instrument to its designer, but like other instruments it cannot be expected to perform impossibilities.

Q. Your idea is that as this meter is suspended in the water, the eddies may cause the tail to turn around at right angles to the regular current, or the way the river is flowing?

A. It is entirely possible that it might turn it as much as at right angles.

Q. Or pretty near so?

A. Or pretty near so.

Q. That would reduce the rotation of the wheel?

A. That would reduce the rotation of the wheel, while the quantity of water passing would not be changed.

Q. And would thereby register inaccurately?

A. And would thereby under-register.

Q. That motion might be horizontal—

A. Or vertical.

Q. —or vertical, or any other way?

A. Or any other way.

Q. According to the conditions of the water?

A. There is always of course the possibility of some obstruction getting upon the meter, which may remain for a short time and then be washed off, as floating grass or string, or even grit and sediment in the water will oftentimes cause a meter to change its rating in a comparatively short time.

The meter being suspended on a cable a long distance below the surface, out of sight, where the only indication that the observer could have of the performance of the meter was the record on the recording apparatus, and possibly the feel of the line, makes it practically impossible for him to tell whether the meter is pointing upstream or in any other direction.

There is a special attachment for the Haskell meter which indicates the direction in which it is pointing; but if the direction current meter was used at all it was only used at certain stations, and not for all the observation.

On the St. Clair, the direction current meter was used in combination with the other meters to give an indication of the direction of the current at certain points in the vertical; but it is a much more complicated machine to use, more liable to get out of order and consequently adds to the trials and tribulations of the observer. I speak from experience.

Q. You have spoken of the difficulties encountered in the use of the current meter in the Niagara River. Do the conditions there compare, are they similar to conditions in the St. Clair and St. Lawrence Rivers?

A. The conditions at the Niagara are very much worse than those encountered on the other rivers. The pulsation of the water in open channels, or in our rivers, is practically always present. I have observed it personally in the Detroit River in the vicinity of Belle Isle, both in current meter work and Pitot tube work, which I have had in the river, where the current will apparently run swiftly for a few seconds and then there will be a perceptible slowing down

for a few seconds, and then again a pulsation which will accellerate it again.

These pulsations were the subject of an extended discussion some years ago before the American Society of Civil Engineers, in which their presence in the St. Clair, the St. Marys River and the Detroit River were referred to by Mr. D. Farr and Henry, as a result of his experience in connection with the original Lake Survey current meter measurements.

Mr. Wilkerson: Have you a reference to the book?

A. I am speaking from memory on it, but the reference is to the discussion of a paper by Emil Kuichling on the resistance of a 24 inch stop valve. I think it is along about 1892. So that the other stations are undoubtedly affected similarly, but to a less degree, and all the gagings may therefore safely be assumed to be less than the true discharge.

Mr. Adcock: Q. Would that affect the determination of the increment?

A. Yes, the increment would be decreased in the same ratio as the discharge itself were decreased, assuming the error in discharge to be the same at different elevations; that is assuming the percentage error of discharge to be the same at different elevations.

To further examine the accuracy of the Haskell meter indications in disturbed water, a series of experiments were arranged for at the Hydraulic Laboratory of Cornell University, wherein the water was measured over a weir, and also simultaneously by a Haskell meter at various points along the experimental canal under varying conditions of disturbance. The meter used was one belonging to Cornell University.

The work was done by Professor E. W. Schoder, in charge of the laboratory, and Professor K. B. Turner, formerly junior engineer in the United States Lake Survey.

The arrangements were made with the kind permission of the dean of the College of Civil Engineering, Professor E. E. Haskell, the inventor of the Haskell meter, to whom I explained the purpose of the investigations and the scope which we hoped to have it cover.

Q. When were these made?

A. They were made during June and July.

Q. Of this year?

A. Of this year; better say during May and June of this year. I am not certain whether they ran over into July or not. My impression is they were all finished during June.

In these experiments, the data of which will be presented later in this case, the meter was found to register from 3 to 10 per cent. too low, depending on the disturbances of the water, although the conditions for accurate measurement were very good.

An error of 6 per cent. in the Niagara gaging would amount to about 12,000 cubic feet per second, and would about account for the discrepancy in the Niagara comparisons with the other three rivers. That such an error exists seems to be certain, for all the information on evaporation from lake surfaces and as to the surface temperatures of the Great Lakes, data upon which are presented in tables LXa to LXII inclusive, disprove the possibility of such evaporation as has been shown to be necessary to account for the small discharge of the Niagara River shown by Complainant's gagings.

Q. Am I correct in understanding this: That the disturbances in the Niagara River are so much greater than those in the St. Clair and St. Lawrence Rivers that you would expect that the meter would under register 6 per cent.

A. More than it does in the others.

Q. More than it does in the other two rivers, is that right?

A. That is the point, that the error is 6 per cent. greater there than it is elsewhere.

Mr. Wilkerson: I do not just get the basis for that 6 per cent. yet, as that answer now stands. Just explain that.

Mr. Adcock: That is my understanding.

Mr. Wilkerson: Yes.

A. In our first experiments at Cornell with the truck, we found at a velocity around three feet per second the meter under registered about 6 per cent. The velocities at Niagara were above three feet per second in general, so that I would expect a somewhat larger under-registration in those observations.

I think I am correct in making that statement of three feet, Mr. Shenehon. If I am in error, will you kindly correct me?

Mr. Shenehon: They are above three feet per second; fully as high as five.

The Witness: For that reason, I would expect the under-registration to be greater than 6 per cent.

Again, the experiments in the actually disturbed water in the canal at Cornell University showed discrepancies as high as 10 per cent., so that it seemed to be quite reasonable to suppose it possible that an error of 6 per cent. could have occurred in the Niagara gagings. That is all there is of it.

Mr. Wilkerson: I understand the point of this to be that if you increase the Niagara measurements 6 per cent. that brings St. Clair, Niagara and Detroit into harmony?

A. Yes.

Q. It makes them consistent, if you increase the Niagara 6 per cent.?

A. Yes, as far as discharge is concerned.

Mr. Adcock: As far as the records of the discharge are concerned?

A. Yes, as far as the recorded discharge, as far as recording the discharges are concerned, they become consistent.

Q. But still you would expect the measurements of the St. Clair and the St. Lawrence to be low under the current meter gaging?

A. I think it is entirely probable. I feel satisfied they are somewhat low.

Mr. Wilkerson: Your point is, if you increase the discharge 6 per cent., you would increase the increment 6 per cent.?

A. No, the increment is an entirely separate thing in this case, because as far as the increment derived for the Niagara River is concerned from the gagings, I consider it absolutely worthless. The relation between lake stage and discharge there is so variable that I think it is absolutely impossible to tie the discharge to the lake stage at the Niagara, the fluctuations are so sudden.

Q. Then I still do not get the point to your 6 per cent.

A. The 6 per cent. is that while it may be possible to measure the discharge of the Niagara River accurately at any particular time, or with a certain degree of accuracy, I will say, my conclusion is that whatever the error is on the others it is 6 per cent. greater at Niagara—or, I will not say that is my conclusion, but I say that if the error at Niagara be 6 per cent. greater than it is in the other measurements, then the Niagara gaging becomes consistent with the other gagings.

But when you talk of increment, that is another proposition entirely, because the increment is dependent upon the measurement of a stage in the lake and the masurement of discharge. Both may be correct, but they may not be the ones that correspond to each other; and with Lake Erie changing position as rapidly as it does, it is impossible that the full effect of any change could be transmitted to the gaging station before the lake had assumed some other position. Therefore I say it is impossible to connect the discharge accurately

with the lake stage, and hence it is impossible to get a correct increment of the Niagara River.

Q. That is your point, that you cannot get the correct increment of the Niagara from measurements there?

A. That is it.

Q. You have to work it either backward or forward?

A. That is my point. There may be some other way of getting it, but you can't get it the way you tried to get it.

Q. I have not examined these last tables you have produced, but have you any place figured out what the Niagara increment would be, assuming you could get it, making this 6 per cent. correction for the readings?

A. I did not make the 6 per cent. correction because I think the determination of the increment has got to be separate from that thing. I have made an estimate; I have an estimated value of the Niagara increment.

Q. I say, assuming that you could get the Niagara increment in the same way that you get the St. Clair, the Detroit and the St. Lawrence increment, correcting the gage readings by the 6 per cent. to which you have referred, have you figured out what the Niagara increment would be?

A. No, because I consider that this method of obtaining the increment at Niagara is absolutely unreliable, and therefore I did not spend any time on it.

Q. You did not spend any time on it?

A. (No response.)

Mr. Adcock: Have you made any comparison of the elevations of the lakes for a period or periods before January 17, 1900, and for a period or periods subsequently thereto? If you have, will you state what comparisons you have made and the results that you have reached?

A. The Drainage Canal so-called was opened in January, 1900. Table LXV of Exhibit 34 shows the elevation and mean elevations of the lakes for 10 years prior and for 10 years subsequent to the opening of the Chicago Drainage Canal.

In the first column is given the year.

In the second column is given the average elevation of Michigan-Huron for the year, and the mean of the 10 years; the first 10 years being 1890 to 1899 inclusive; the second 10 years being 1900 to 1909 inclusive.

The third column gives the same information for Lake St. Clair. And the fourth column the same information for Lake Erie.

From this it appears that during the decade next prior to

the opening of the Sanitary and Ship Canal, the average elevation of Lakes Michigan-Huron was 580.342, and that during the decade next following the opening of the Drainage Canal, the elevation was 580.665, showing a rise of .323 feet, or approximately 4 inches.

The mean elevation of Lake St. Clair for the decade preceding the opening of the canal was 575.013 and the mean elevation for the decade following the opening of the canal was 575.255, showing an increase of elevation during the second decade of .242 feet, or approximately 2.8 inches.

Mr. Wilkerson: This table is just a table of——

A. Of actual readings.

Q. Without any attempt to take into consideration any element of change of fact?

A. No, just setting forth the fact.

Mr. Austrian: It is putting it in concrete form.

The Witness (continuing): The mean elevation of Lake Erie for the decade preceding the opening of the canal was 572.012, and the mean elevation of the same lake for the decade following the opening of the canal was 572.210 showing the rise of the lake the second decade over that in the first of .198 feet, or about 2.3 inches.

It is further to be stated that a comparison of the decade next preceding the opening of the Drainage Canal with any decade since the opening of the Canal will show the lakes to have been on the average at a higher elevation during the decade since the opening than during that preceding; and that a comparison of single yearly elevations will show that in no case since the opening of the Drainage Canal has the average annual elevation of the lakes been so low as it was during a single year preceding the opening of the canal.

Mr. Adcock: What increments do you derive for the various rivers? Take the St. Lawrence, Niagara, Detroit and St. Clair Rivers, based upon the facts already in evidence?

A. Considering all the evidence in this case and the fact that, as heretofore stated, the increments derived by direct mathematical computation have been in every case lower than the true increments which would exist, for reasons heretofore stated, the values of the several increments for normal open season conditions appear to be, for the St. Lawrence, about 30,500 cubic feet per second, for the Niagara not less than 34,000 cubic feet per second, for the Detroit about 32,000 cubic feet per second; for the St. Clair about 29,000 cubic feet per second.

Q. When you say "appear to be," do you mean there that is the conclusion which you have reached from the investigations you have made and the facts which you have set forth in your evidence heretofore?

A. Yes, I mean by that that I do not consider that any information that we have is sufficiently accurate or positive to enable any one to say what they are. It is my belief that they cannot be less than the figures which I am giving.

Mr. Wilkerson: Is it your opinion that they are more?

A. I think that the chances are very good that they are more.

Q. I want your opinion. What is your best judgment?

A. Well, I am very well satisfied that they are more rather than less.

Q. I want a statement as to whether you think they are more; if so I want to know how much more; your professional judgment on that.

Mr. Austrian: Whether that is your best professional judgment.

Mr. Wilkerson: If that is your judgment I would like to have you say so.

Mr. Adcock: You mean——

Mr. Wilkerson: Let him answer the question.

Mr. Adcock: You mean from the records?

Mr. Austrian: From the facts that appear in evidence and the deductions made.

Mr. Wilkerson: He is now testifying to a conclusion as an expert. I do not want him to leave the conclusion unfinished. I want him to give his best opinion as an engineer what the correct figure is, so that I may know what I am to go on as a basis for cross-examination.

Mr. Adcock: You mean from the data and material that he has at hand?

Mr. Wilkerson: Yes.

Mr. Adcock: Or what his opinion may be from general conditions.

Mr. Wilkerson: No, I mean his opinion, in the way in which he has reached his opinion, whatever it may be. He has reached an opinion. Now I want to know what it is.

A. I do not think that the increments are any less than the figures which I have given here, and I do not think that they would be more than 10 per cent. greater.

Mr. Adcock: Have you made any calculations from the increments that you have above stated as to the possible effect

upon the lakes of a diversion of 10,000 cubic feet per second? If so state what the results of your computations are?

A. For a diversion of 10,000 cubic feet per second, Lake Ontario would be lowered about 0.327 feet, or slightly less than 4 inches. Lake Erie would be lowered about 0.294 feet or a little more than 3½ inches. Lake St. Clair would be lowered 0.312 feet, or a little less than 4 inches. Lake Michigan-Huron would be lowered 0.345 feet or a little more than 4 inches, about 4⅛ inches.

Mr. Wilkerson: In view of the fact that this testimony is likely to be used in the consolidated case, it would be very convenient if you would give us the figures for 10,000 or 14,000 and 16,000. Of course it is a mere matter of computation, but it would help if we could have the table with those figures.

Q. You haven't them prepared for 14 or 16?

A. No.

Mr. Adcock: As I understand it, the answer to the question that I just asked you is based upon the increments which you have derived there?

A. Yes.

Q. Is that correct?

A. It is.

Q. Would the effect be the same, that is be in the same ratio, for a diversion of over 10,000 second feet up to, say, 14,000, or for any amount under 10,000 feet?

A. Yes, for a diversion of 14,000 feet, the effect would be 1.4 times that which I have given; and for a diversion of, say, 7,000 feet, it would be .7.

Q. Have you considered the question of compensating for any possible lowering of the lake levels?

A. Yes, I have.

Q. Will you state what conclusions you have reached with reference to that subject?

Mr. Wilkerson: I object to the word "possible." I think now it appears that there will be a lowering.

Mr. Austrian: You mean possible lowering by diversion?

Mr. Adcock: By diversion.

The Witness: Or otherwise; they compensate for any lowering.

Mr. Austrian: Yes.

The Witness: The backing up of the upper Detroit River by the Livingstone Channel works and the raising of Lake Ontario by the Gut Dam in the St. Lawrence illustrate the

ease with which it is possible to compensate for diversions from Lake Michigan.

For example, referring to Williams Exhibit 10, it would be entirely feasible to close the Stony Island Channel, and thereby reduce the discharge of the lower Detroit River by about 11,000 cubic feet per second, which would raise Lake St. Clair in the neighborhood of two inches.

The capacity of the Trenton Channel, which was found to be about 36,000 cubic feet per second, could be easily reduced to an extent equal to the reduction of the Stony Island Channel, or even more, by a judicious filling in of material, and thus the compensation of Lake St. Clair obtained for the diversion at Chicago.

The cost of this filling, based upon the prices paid for moving the material in the vicinity of the mouth of the Detroit River, would be about $250,000. The approximate discharges of the several channels at the mouth of the St. Clair River, as measured by the Lake Survey, and given in Williams Exhibit 23, are as follows:

Chenal Ecarte, 11,600 cubic feet per second.

Blind Channel, 400 cubic feet per second.

Bassett Channel, 12,000 cubic feet per second.

South Channel (the one connected with the canal), 59,000 cubic feet per second.

Middle Channel, 33,000 cubic feet per second.

North Channel, 78,000 cubic feet per second.

This makes a total of 194,000, which represents a rather low stage of the river.

From these discharges it appears that either the North or the Middle Channel might easily be restricted to the extent of 15,000 cubic feet per second without detrimental effect, and this would compensate for the lowering of Lake Michigan-Huron by the contemplated Chicago diversion.

The cost of this compensation would be about $500,000, which makes a total of about $750,000 to compensate for the lowering of Lakes-Michigan-Huron, the St. Clair, and the St. Mary's, St. Clair and upper Detroit Rivers.

The construction of the Gut Dam in the St. Lawrence has already compensated for the abstraction of water from Lake Ontario; and the International Waterways Commission are submitting a report upon works to regulate the level of Lake Erie, which, if constructed, would provide for a compensation for the diversion from Lake Erie and the lower Detroit River.

Mr. Adcock: I think that is all. I submit the witness for cross-examination.

Whereupon an adjournment was taken to Friday, July 18th, at 10 o'clock a. m.

Friday, July 18th, 10 a. m.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Cross-Examination by Mr. Wilkerson.

Q. How much time have you spent on this case, Mr. Williams?

A. I could not say.

Q. Well, approximately?

A. When was the case begun?

Q. Maybe we can get at it another way: What is the rate of compensation at which you are employed in the case?

A. I am employed at $100 a day when in court; when in conference away from home, $75 per day; $50 per day for office work at home.

In addition to that, there is the services of my office. If you want to get at the time, I can work it out.

Q. I would like to know within reasonably accurate limits how much time you have expended in these different kinds of work.

Mr. Adcock: You mean on this case?

A. I began work in the case very shortly after matters got down to business; I don't know how long after the bill was filed, but I recall it in this way that I had a letter from the Lake Survey Office asking me for my terms; or rather from Major Keller, asking me for my terms in connection with the case. And after thinking it over, as I remember, I did not feel that I wanted to take that side of the case. And the same day I got a letter from the Sanitary District asking me if I would assist them; and I went over to Chicago immediately and began work on the case then. My recollection is that was in November or December but I can't say what year. It was the year that the suit started. I think the bills were filed along in August or some such time as that and I began then.

Since that time, I have devoted a considerable amount of my time, from time to time, as things got warm in the case and they got ready to do something, I would go to work and put in

perhaps the major part of my time for a month, with my office. And then things would be postponed, and I would drop it. Afterwards it livened up again and I would go at it some more.

Mr. Wilkerson: I would like to know if you have your memoranda from which you can give us the information as to the amount of time you have actually put in?

A. I haven't it here in New York; it is in my office. I did not imagine that would be asked for or I might have brought my time sheets for the past five or six years.

Q. It is a matter you can easily determine?

A. Yes.

Q. It involves, as you stated on your direct examination, the expenditure of perhaps half your time for four years, as I understood your statement to Mr. Adcock?

A. I don't think I put it quite as strongly as that, though I might have.

Q. That is my recollection of what you said to Mr. Adcock, that you spent about half your time for four years in the study of this case?

A. I do not believe——

Mr. Austrian: No question of time was asked him.

Mr. Wilkerson: Let him finish the statement.

The Witness: I don't remember the statement at all, but that would indicate more time than I think I individually put on the case.

Q. Your office has put in a good deal of time?

A. My office has put in a good deal of time.

Q. How much time has it put in?

A. I can't say that, because there have been times for three months at a time when we have had active work on this case continuously.

Q. How many men have you had assisting you?

A. I have had anywhere from two to six or eight; not for as long periods as that. I have frequently had two men working on it continuously. I have had two men working continuously; I don't say frequently because that did not cover periods of more than a month or six weeks now and then.

Q. Maybe we can get some idea of the amount in this way: Do you remember how much has been paid you up to the present time, for the combined services of yourself and your office?

A. I think it is somewhere in the neighborhood of $10,000 or $12,000.

Q. That does not cover the services rendered to date?

A. Does not cover the services rendered at the last hearing nor for a considerable time before that. I was paid up to some time——

Q. That would come to about what time, the first of this year?

Mr. Adcock: I think about the middle of March.

A. I think I can tell that; I think that bill either came to the first of March——

Mr. Wilkerson: I will take your statement of the time spent up to the 1st of March.

Mr. Adcock: I think practically that was the time. It might have been later than that or earlier. It was about that time though.

The Witness: That bill apparently was until the 1st of March.

Mr. Wilkerson: To the 1st of March?

A. I think so. I won't say positively.

Q. For what you and your office have done since the 1st of March, the bill has not yet been rendered?

A. The bill has not yet been rendered. I have not figured it up, as a matter of fact.

Q. That would include all the time you spent in the immediate preparation for your own testimony, and in giving it?

A. Yes.

Q. And the services of the employes of your office?

A. Yes.

Q. In working with you?

A. Traveling expenses also.

Q. Compiling the data you have given here?

A. Yes.

Q. And of course your traveling expenses?

A. Yes.

Q. You haven't any idea how much they would amount to, have you? I do not ask you to bind yourself, in a law suit against the District?

A. I think that the services since the 1st of March have amounted to somewhere between $6,000 and $7,000, is my guess, without figuring it up.

Q. That would make your bill for work up to date in the neighborhood of $18,000 or $20,000?

A. I think that is somewhere near right.

Q. If that figure is not approximately accurate, I wish you would refer to your records when you get back.

A. It is approximately accurate.

Q. Refer to your records when you get back to Ann Arbor, and give us the correct figure later on.

Now you have, as a result of this work which you have been doing, you have arrived at or have accomplished certain net results in this case from your standpoint, as I understand it. Let us see whether I am correct or not: As to the effect of the diversion of 10,000 cubic feet of water at Chicago upon the lake levels as measured in the St. Lawrence River, the figure of the International Waterways Commission was 4¼ inches, wasn't it?

A. I do not remember.

Q. I wish you would refer to that to be sure. That is upon the level of Lake Ontario.

A. You refer to the level of Lake Ontario, in the St. Lawrence River, I understand.

Q. Yes, and for convenience I refer to page 76 of the report of the International Waterways Commission for the year 1910, Table XXXVII.

A. That is the figure given in that report.

Q. The figure which was given by Dean Shenehon, witness for the Government in this case, for the effect of the diversion of 10,000 cubic feet per second at Chicago was 4⅛ inches, was it not?

A. I do not remember. I can refer to it.

Mr. Austrian: That is for Lake Ontario?

Mr. Wilkerson: Yes.

The Witness: I assume that is correct. You asked about the St. Clair, about Michigan-Huron?

A. No, St. Lawrence. Mr. Shenehon's figure, as I recall it, was given at Ogdensburg?

A. According to Complainant's Exhibit 2, the scale indicates for a diversion of 10,000 cubic feet, something over 4 inches. I should say between 4⅛ and 4¼ inches for the Ogdensburg gage, as I read the exhibit.

Q. Your own figure for the effect of that diversion, as I recall your testimony, is that it is slightly less than four inches?

A. Yes, sir, I think that was my statement; yes, just under four inches.

Q. It is what you call four minus. That is to say it is slightly less than four inches, and that is your opinion as to the effect of the diversion of 10,000 cubic feet per second upon

the level of Lake Ontario as determined from the observations in the St. Lawrence River, is it?

A. That is my opinion and my best judgment as to the maximum effect of the diversion of 10,000 cubic feet at Chicago upon the levels of Lake Ontario, based upon all the information which I have been able to secure up to date bearing upon the discharge of the St. Lawrence River and its increment.

Q. Well, now, what is your best judgment as an engineer as to the effect of that diversion?

A. That it will not be more than 4 inches.

Q. And that it will be at least within 10 per cent. of that figure, as I understood you yesterday?

A. I don't think I want to put it as strong as that. I would be surprised if it should be more than 10 per cent. less than that figure. But I conceive that it might be.

Q. Your best judgment as an engineer then is that you would be surprised if there was a difference of more than 10 per cent.; you think there would not be more than a variation of 10 per cent. from that figure?

A. I would say my judgment at the present time is: That effect will be between 3½ and 4 inches.

Q. That is your best opinion as an engineer?

A. That is my best opinion at the present moment.

Q. As to the effect of the diversion of 10,000 cubic feet per second at Chicago upon the level of Lakes Michigan-Huron, the figure of the International Waterways Commission is 6½ inches, is it not?

A. Yes.

Q. The testimony of Dean Shenehon for the Government was that five inches plus was the lowest figure which could be accepted as expressing the effect of that diversion upon the levels of Lakes Michigan and Huron?

A. In his opinion.

Q. What is that?

A. In his opinion.

Q. He gave that as his opinion?

A. Yes.

Q. That five inches was the lowest figure which would express it. Your statement of the effect of the diversion upon the levels of Lakes Michigan-Huron is that in your opinion the effect of the diversion is 4⅛ inches plus. Am I right in that?

A. Approximately.

Q. Well, I want to get—if it is not 4⅛, if there is any other fraction, what is it?

A. Well, that is the closest, I guess the closest that you could get; slightly over 4⅛.

Q. Between 4⅛ and 4¼ inches?

A. Yes, very close to 4⅛.

Q. That is your best professional opinion as an engineer with reference to the effect of the diversion of 10,000 cubic feet per second at Chicago upon the levels of Lake Michigan-Huron?

A. That it will not be greater than about 4⅛.

Q. The same as you said about the other figure, you would be surprised if it should be determined that it was more than 10 per cent., less than that?

A. At the present time, I would put the limits to that at about three and three-quarters.

Q. That is, it could not be less than 3¾?

A. I think it could, but I don't believe it would be.

Q. Your best opinion is it would not be?

A. My opinion at the present time, in the light of such information as I have is that it is not less than 3¾.

Q. What I want is your best judgment.

A. That is the best I can give you.

Q. Your best judgment as an engineer as to the effect of that diversion?

A. All right.

Q. And the figures which you state, 4⅛ to 4¼, with the possibility of a diminution down to 3¾ is your best opinion?

A. Yes.

Q. As to the effect of the diversion of 10,000 cubic feet of water at Chicago upon the level of Lake Erie, I understand the figures of the International Waterways Commission to be 5⅝ inches?

A. That is as stated in the report.

Q. The statement of Dean Shenehon, the witness for the Government, was that the effect of the diversion of the 10,000 cubic feet upon the level of Lake Erie was 5¼ inches?

A. That appears to correspond with the scale on Exhibits 3 and 4.

Mr. Adcock: Complainant's exhibits?

A. Complainant's Exhibits 3 and 4.

Mr. Wilkerson: Your best opinion as an engineer as to the effect of the diversion at Chicago upon the level of Lake Erie is, as I understand you, 3½ inches?

A. Yes. I put 3½ inches as the maximum limit.

Q. What do you put as the minimum limit?

A. Well, the increment of Lake Erie is so doubtful as to what it is, that is the conditions make its determination so uncertain, that I never have really given very serious thought as to what the upper limit of increment and minimum limit of diversion might be.

Q. What is your best opinion as an engineer as to the minimum figure that could be assigned as representing the effect of that diversion upon Lake Erie?

A. Well, I think I would say at the present moment that it would not be less than two inches.

Q. It would not be less than two inches; and that 3½ is your best judgment, while it might be as low as two?

A. Th ee and one-half is my judgment of the upper limit?

Mr. Austrian: That is the maximum?

A. The maximum.

Mr. Wilkerson: That is to say, it is your opinion as an engineer that the effect of the diversion of 10,000 cubic feet at Chicago would be less upon the level of Lake Erie than it would be upon the level of either Lake Ontario or the level of Lakes Michigan-Huron?

A. That is my opinion.

Q. And it is your opinion that the conclusion of the International Waterways Commission in assigning to the effect upon Lake Erie a higher figure than upon Lake Ontario is an erroneous conclusion?

A. I believe so.

Q. When did you first confer with Mr. Stearns about this case?

A. Some time early this year.

Q. Approximately?

Mr. Adcock: You conferred with him about the early part of February.

Mr. Wilkerson: How many days in the aggregate have you spent in conference with Mr. Stearns?

A. Prior to his appearance, that is prior to the last hearing, I spent the time from Ann Arbor to Buffalo on the Wolverine, and during the hearing, when I was on the witness stand, and during the days that you gentleman were in Washington, we were all working together on certain phases of this question; and such other time—such other conferences as have been had with Mr. Stearns, limited to a trip down the Sanitary Canal along in May or June, in which there was a

large party of us. Mr. Stearns was along, and in the evening we had a conference of about an hour with various experts, on this case.

There has been no private conference at which Mr. Stearns and I were the only ones present, so far as I can remember, except that first one on the Wolverine, when I presented to him an outline of my testimony and asked him to examine it and see whether he could be of assistance to us in this case.

Q. When you said Washington, you meant New York?

A. No, you and Mr. Adcock went down to Washington and left us there in New York, and we had a three days' recess.

Q. You mean the time when Mr. Adcock and I went to Washington?

A. Yes. When we were in New York, Mr. Stearns was there, and we spent that time in working up data in this case.

Q. How many days all together would you say it amounted to?

A. If you count that in, it might amount to four or five days.

Q. When did you first confer with Mr. Freeman about the case?

A. I conferred with Mr. Freeman at Niagara Falls the day after I conferred with Mr. Stearns on the Wolverine. I got off at Buffalo and went up to Niagara Falls that night to meet Mr. Freeman, and met him the next morning and had a conference of about 20 minutes with him on the subject, and then later in the afternoon had another conference of about, something less than an hour. The next time I saw him was when he appeared here in New York.

Q. Prior to the time when you conferred with Mr. Stearns and Mr. Freeman, are you aware of any engineer who has ever studied this question, who has stated the conclusion that the effect of the diversion of this water would be greater upon Lake Ontario than it would be upon the level of Lake Erie?

A. I don't recall anybody.

Q. And up to that time was it not the unanimous opinion of engineers who had studied this question that the effect of the diversion of this 10,000 cubic feet would be greater upon Lake Erie than it would be upon Lake Ontario?

A. I don't know of any engineers who had studied this question up to that time, outside of those connected with the United States Lake Survey and the International Waterways Commission; and I assume that their opinions are represented by their published reports.

Q. Who are the engineers, as you now recall them, who were connected with the Lake Survey Office, who studied this question?

A. Mr. E. E. Haskell, Mr. Shenehon, Mr. Russell, Mr. Ray. I think those are all you would really put in that class, outside of the Engineer Officer.

Q. Mr. Sabin?

A. I beg your pardon, I should have included Mr. Sabin. That was an oversight; I would say Mr. Sabin also. He should have been put early in the list because he was one of the first ones.

Q. How about Mr. Wilson?

A. I was going to put him with the International Waterways Commission. His study of this thing did not take place until after he went with the International Waterways Commission, so far as I am aware. He worked on the discharge of the St. Mary's River, but I am not aware that he gave any special attention to the general problem until he went with the International Waterways Commission.

Q. Didn't Mr. Wilson investigate slope conditions in the Niagara River in 1903?

A. I think he did, but as I say, it is my impression he did not give any particular study to the general problem.

You can bring in a list of men; I can identify probably 20 who have been connected with this work in one way or another, and have performed certain parts of it, but when you ask who made a study of it, I think the list I gave practically completes it, outside of the Engineer Officers themselves and who I am very much in doubt——

Q. How about Mr. Blanchard?

A. I was not aware that Mr. Blanchard had made any study of the proposition as a whole. Mr. Blanchard was engaged on the St. Clair gagings and also the Detroit River, and then left the service shortly after.

Q. Who are the engineers, who by reason of their connection with the International Waterways Commission have given study to this question?

A. Well, Mr. E. E. Haskell has principally. I don't know to what extent General Ernst has given it study. He may or may not have devoted particular attention to it. And Mr. Wilson, the Secretary of the Commission, has given it a great deal of attention.

Q. Any Canadian engineers, with whom you are familiar?

A. I think that Mr. Stewart has.

Q. Any one else, any other Canadian engineer that you know at all?

A. I do not think that Mr. Coste, who was formerly the engineer member, is likely to have given very much attention to this phase of the question.

Q. Did any one connected with the Deep Waterways Commission ever make any study of this question?

A. I can't be certain whether the Deep Waterways Commission considered the effect of the diversion at Chicago. Their problem was the question of a deep waterway from the lakes to tide water, and they considered various problems connected with that, and incidentally, probably, the Chicago diversion. But at the time that they were working, there was not sufficient definite information to enable a very comprehensive study of the problem to be made.

I think it is probable they did make an investigation along the line of this effect, but I don't recall what it was.

Q. Without regard to whether the effect of the diversion was concerning 10,000 cubic feet per second, they did make a study of the question of the relation between lake levels and the volume of discharge in these respective rivers, did they not?

A. They did in regard to the Niagara, for the reason that they were very suspicious of the supposed outflow of the Niagara River, they having had their attention drawn to the conditions which have been pointed out in this case, of the inconsistency of the supposed river discharge with the discharges apparent in the other rivers, and the later gagings of the upper rivers having reduced the apparent discharge of those rivers slightly, helping to bring the results more nearly into harmony. And the earlier Niagara gagings were undertaken by the Board of Engineers on Deep Waterways in an attempt to ascertain what the discharge of the Niagara actually was, in order to determine the effect of the proposed regulating works upon the level of Lake Erie. And of course incidentally with that, they considered the effect of those works upon Lake Ontario.

As I said before, I do not know to what extent the diversion of Chicago entered into that problem. Of course it was a study of the same thing, in its essentials, but at that time, if my memory serves me correctly, they did not have the St. Lawrence gagings.

Q. I understand that the net result of your work is the expression of the opinion by you as an engineer that the fig-

ures which have been deduced by these various engineers who have been mentioned, as representing the effect of the diversion of water, are incorrect?

A. I think they are in error.

Q. And so far as the Niagara River is concerned, or rather so far as the effect upon the level of Lake Erie is concerned, they have been in error to an extent of between 60 and 100 per cent. of the figure which you state as the correct figure.

Mr. Austrian: No, you do not mean that.

Mr. Wilkerson: Yes.

Mr. Austrian: No, it is the difference between 2 1/5 and 5⅞.

Mr. Wilkerson: He made his figure 3½. Their figures were 5⅞. The difference between 5⅞ and 3½ is 2⅜. What per cent. of 3½ is 2⅜—what per cent. of 5⅞?

The Witness: I have answered the question.

Mr. Wilkerson: The witness gets my point.

The Witness: According to my best judgment the effect of the diversion as reported by the International Waterways Commission is in error approximately 100 per cent.—or no, I should say 50 per cent. when speaking of them.

Q. When speaking of their figures?

A. When speaking of their figures, it is 50 per cent., and 100 per cent. of mine.

Q. You get a figure about half of theirs?

A. I get a figure about half of theirs.

Mr. Austrian: Three and one-half is not a half of 5⅞.

Mr. Wilkerson: He said 2 to 3½.

Mr. Austrian: He said not less than two nor more than——

Mr. Wilkerson: I was assuming the average of the two limits. I wanted to get his conclusion.

Mr. Austrian: I beg your pardon for interrupting. I didn't understand.

Mr. Wilkerson: Stated in as simple a way as possible, so that we will understand what the net result of his computation is.

Q. Now, as another one of the net results of your work in this case, you have suggested, if I understand it, that there has been a lowering of the level of Lakes Michigan and Huron by the dredging which the Government itself has done in the St. Clair and Detroit Rivers?

A. Not only suggested it, but I have affirmed it and I reaffirm it.

Q. So that we may have it here in the record, what is your opinion as an engineer as to the extent to which the levels of Lakes Michigan and Huron have been lowered by the dredging which has been done in the St. Clair and Detroit Rivers?

A. At least .6 of a foot.

Q. By that you mean .6 of a foot is the lowest figure?

A. Yes, I mean it has not been lowered less than that in my judgment.

Q. What is your maximum figure?

A. Oh, about twice that, 1.2, say.

Q. Is it your opinion that that is merely a possibility, or is that your best opinion as an engineer that it has resulted in a lowering of 1.2 feet?

A. I think that is the upper limit.

Q. That is to say it is a possibility?

A. It is a possibility.

Q. But not probable?

A. I would say that it is not probable the effect has been more than a foot. I hardly think it is possible it has been more than 1.2.

Q. So between .6 of a foot and a foot——

A. Below a foot is where I really think that the result is to be found.

Q. Now, I understand as another one of the results of the work which you have done in this case, you have presented a statement and a table which show, in your opinion that since the diversion of water through the Chicago Drainage Canal, the level of Lakes Michigan and Huron has actually increased?

A. I think that is correct. They have actually increased, placing my faith upon the records of the United States Lake Survey.

Q. Is it your opinion as an engineer that the diversion of water by the Sanitary District at Chicago has had the effect of raising the levels of the lakes?

A. Certainly not.

Q. What then, so far as the question of effect upon the lake levels is concerned, is the weight which in your opinion is to be given to that table?

A. Merely a statement of fact?

Q. Merely a statement of fact? That is Table LXV?

A. I guess so. That is the table is a statement of fact.

Q. In other words, what inference, as an engineer, is it

your intention that the court at the hearing of this case shall draw from your table number LXV, so far as it throws light upon the question of fact which is involved in this case?

A. That the lakes are actually higher now than they were before the diversion. That is all.

Q. In your opinion, does it throw any light at all upon the question of fact as to the effect of diversion?

A. None whatever.

Q. None whatever?

A. (No response.)

Mr. Austrian: May I ask you this question, to clear up the record a bit: You do not question the accuracy of that Table LXV, as I understand it; that is that the lake levels are higher now than they were in 1900?

Mr. Wilkerson: I am the counsel. I would not care to question the accuracy of the table. I am merely trying to find out from the witness what aid he expects the court in this case to get from his table number LXV, from which he has reached a conclusion of fact.

Mr. Austrian: Just for the sake of putting it in readable form.

Mr. Wilkerson: In other words you put it in there because counsel told you to?

A. They didn't tell me to, but they asked me to; and it being a plain statement of fact, with no opinion connected with it, I saw no reason why it should not be put in.

Q. As a matter of fact, you say, when asked today about it, that it did not have the slightest thing to do with the facts in this case?

A. I don't think I would put it as strong as that.

Mr. Austrian: I object to that.

Q. You took it from records compiled by the Government itself?

A. I did, and I believe the table to be a correct statement of fact. That is all there is to it.

Mr. Wilkerson: Isn't it perfectly obvious to you as an engineer that the only effect which could result from the use of that table would be somebody might use it in an attempt to confuse the court as to the testimony in this case.

Mr. Austrian: That is objected to. I ask the witness not to answer the question.

Mr. Wilkerson: The witness, under the instruction of counsel, declined to answer the question.

Q. I understand as a result of the work which you have

done in this case, another one of the net results is that you have indicated a scheme of compensation which might be employed for the purpose of bringing the level of the lakes back to the point where they would be if water was not diverted at Chicago?

A. Yes.

Q. And that scheme in general, as I understand it from your testimony yesterday, and I have not had the benefit of reading your testimony, so I am speaking from memory, involved the filling in of certain channels?

A. Portions of certain channels.

Q. Portions of certain channels. Those channels which it is proposed to fill in are navigable channels, are they not?

A. Yes, and the proposed filling would not interfere with navigation.

Q. That is to say in your opinion it would not?

A. That is the fact——

Q. It would be the placing of material in a navigable channel of the United States?

A. Yes.

Q. That is what it amounts to, isn't it?

A. Yes.

Mr. Adcock: You started a sentence that you did not finish.

A. I said it would not be an interference with navigation.

Mr. Wilkerson: But of course whether it would interfere with navigation or not is something for the Government itself to determine.

Mr. Austrian: I object to that. That may be a conclusion of law from your viewpoint, but you are asking this witness to testify to facts and not law.

Mr. Wilkerson: I am satisfied if I understand from the witness that the scheme of compensation involves the filling in of channels which are navigable.

The Witness: Yes, it involves the adoption of the same plan which has been adopted by the Government in the lower Detroit River.

Q. In addition to the contradiction of the figures of the Lake Survey and the International Waterways Commission, the statement as to the effect upon the level of Lakes Michigan and Huron by the dredging which the Government itself has done in the St. Clair and Detroit Rivers, the scheme of compensation which has been suggested and the statement as to the actual condition of the Lake levels since the diversion of the water at Chicago, do you now recall any other

general propositions that you have put forward here as representing your conclusions in this case? I am not now speaking of comments upon methods of computation but I am speaking of what might be called ultimate net results of your work.

Mr. Adcock: Do you understand the question?

A. It is a little hard to say just where you would draw the line.

Mr. Wilkerson: He understands it.

The Witness: It is a little hard to say just where you draw the line between what are, as you say, the ultimate facts and the subordinate facts; the ultimate conclusions and preliminary conclusions.

Q. Indicate a subordinate conclusion, which in your opinion is not covered by one of those general propositions which I have stated?

A. The proposition that would seem to me might be included in that category, although quite possibly would be relegated to a minor position would be that the gagings at Niagara cannot be depended upon for the establishment of the increment that comes in the——

Q. That comes in the criticism of the other conclusions as to the effect of the diversion. And the basis for your conclusion of fact is that you have an idea as to the value of the Niagara measurements?

A. Yes.

Q. Do you think of anything else now except that?

A. So far as I recall the testimony, and dividing it into the categories as you suggest, I think you have covered it; although I would like to add this: That the showing that the International Waterways Commission and the Lake Survey are in error in the effect of diversion is not what I have in mind in thinking of this proposition. I would have been very glad to have agreed with them in their conclusions.

Q. But you did not?

A. But I did not, and my conclusion is that the effects are so and so; not that the other fellow's are wrong.

Q. Of course if your conclusions are right they are necessarily wrong?

A. Yes, but I do not have to conclude that.

Mr. Austrian: That is a polite way of giving the lie direct.

Mr. Wilkerson: I think the counsel on the other side has stated the effect of it accurately.

Q. In speaking of your experience as an engineer, I think

you mentioned that you had been connected with another phase of litigation, to which the Sanitary District was a party?

A. I was.

Q. That was the case of the State of Missouri versus the State of Illinois and the Sanitary District of Chicago?

A. It was.

Q. A suit, an original bill as I recall it, brought in the Supreme Court of the United States?

A. It was.

Q. About 1903, or rather your testimony was in 1903?

A. It was about that time, yes, I think 1903. I think that is correct.

Q. What was the question that was involved in that case?

A. It was an application for an injunction on the part of the State of Missouri for the benefit of the City of St. Louis to restrain the City of Chicago from discharging its sewage into the Illinois River, on the theory that it would pollute and injure the water supply of the City of St. Louis.

Mr. Austrian: And thereby promote disease and be a public nuisance and so forth.

Mr. Wilkerson: Q. You were retained in that case as an expert witness for the State of Missouri?

A. I was.

Q. How much time did you spend on that case?

A. About a month.

Q. Including the time of preparation and testimony, at the same rate of compensation that you have in this case?

Mr. Austrian: I object to that question because the law is that it is perfectly permissible to inquire as to the compensation of an expert witness in the case at bar; not in other cases; and especially where the compensation is not paid by the same person to the controversy.

Mr. Wilkerson: Let him answer, subject to objection.

A. I think my charge was on the same basis as this.

Q. That it amounted to about $3,000 all together?

A. Something of that sort.

Q. That is approximately the figure?

A. Yes.

Q. Your testimony in that case was before the Supreme Court, was it not?

A. It was.

Mr. Austrian: You do not mean before the Supreme Court. You mean before a commissioner?

Mr. Wilkerson: It was taken before a commissioner and was in the record when the case was argued before the Supreme Court, so that it was before the Supreme Court.

Mr. Austrian: Yes.

Mr. Wilkerson: Q. You are familiar with the printed record in that case, are you?

A. I have seen the volumes, but I think I have not seen the testimony.

Q. I direct your attention to pages 2467, 2468 and 2469, from which I shall read into the record and ask you—

Mr. Austrian: Whose testimony?

Mr. Wilkerson: Testimony of Gardner Stewart Williams, taken at the Southern Hotel, St. Louis, Missouri, at 2 p. m., on Tuesday, the 26th day of May, 1903. Present: The commissioner, and the same counsel representing the respective parties. That was John Hamline and Mr. Todd, as I recall it, for the State of Illinois and the Sanitary District, and General Crow and Judge Johns.

Mr. Austrian: Is that testimony in abstract form or verbatim?

Mr. Wilkerson: It purports to be question and answer.

The Witness: I think it is verbatim.

Mr. Wilkerson: Q. I ask you to look at the portions I have marked on pages 2467, 2468 and 2469. I ask you to state whether or not, according to your best recollection, that is the testimony, or part of the testimony which you gave on that hearing?

Mr. Austrian: That is the questions that were put and the answers given.

Mr. Wilkerson: The questions that were put and the answers given as there set down according to his best recollection.

A. I think that is my testimony.

Q. I now invite your attention to the following, page 2467: "Q. Mr. Williams, I will ask you as an expert on water supplies, for cities and towns, passing your opinion upon the subject broadly, in your judgment is there any present or impending or future danger to the people of the State of Missouri using the waters of the Mississippi below the mouth of the Illinois for drinking purposes, which danger would be due to the discharge of the mixed sewage of the Sanitary District of Chicago and the waters of the Drainage Canal into the

Illinois River other than the infection with typhoid fever germs of the waters of the Mississippi River."

Mr. Austrian: We make special objection to the question put, and the answer thereto, and all subsequent questions because thus far it does not appear that that testimony would tend to prove any issue involved in the present controversy. And it is stipulated that all this testimony, question and answer, may go in subject to objection.

Mr. Wilkerson: We have a stipulation that was made at the outset of the testimony, that any objection which did not involve the form of the question, or something which could be corrected at the hearing, might be pressed at the hearing of the case with the same effect as if there made; and it was understood that that applies not only to questions on the direct examination, but, of course, to the questions on cross-examination.

Mr. Austrian: Very well.

Mr. Wilkerson: I would think, however, that if the objection is that it is not proper cross-examination, and the objection were one which could be obviated at the taking of the testimony before the commissioner, it would be proper to indicate the reason why it is not proper cross-examination, so that if it can be corrected, we may have the opportunity of doing so.

Mr. Austrian: You would have to call him as your own witness, but we do not make that point.

Mr. Wilkerson: Your objection is the particular objection.

Mr. Austrian: Yes, you could cure that by merely calling the witness as your own.

Mr. Wilkerson: Yes.

Mr. Austrian: We do not make that objection.

Mr. Wilkerson: Your objection is that the testimony itself is inherently incompetent.

Mr. Austrian: Yes; does not tend to prove any issue, so far as I know anything about it. It might develop later that it does tend to prove the issue.

Mr. Wilkerson: (Q.) (Continued.) "A. In the history of water-borne diseases in America, while typhoid fever plays an important part, it comes far short of playing the entire part. Not only Asiatic cholera, but a large number of our common American diseases are undoubtedly transmitted through the water. Among those germs which have been found to have a considerable length of existence in the water

are the germs of diphtheria, tetanus and anthrax, as well as a considerable number of germs which are derived from the diseases of the lower animals.

The germ of anthrax, for instance, is capable of producing very serious disease in both man and beast, and there have already occurred in the City of St. Louis cases of anthrax, one of which has been traced apparently to the water supply, and the germ of anthrax is reported to have been already found in the waters of the Illinois River. Anthrax is primarily a disease of the lower animals, and in France, where it has been specially prevalent, in some provinces it has been no uncommon thing for 10 per cent. of the sheep to be destroyed by it in a single year.

A peculiarity of anthrax is the remarkable length of life of the spores or seeds—whichever you may choose to call them—in water, they having been known to exist in it not only for months, but for years, and are practically indestructible. Should anthrax be present among cattle which are daily slaughtered in the Chicago Stock Yards, and from them be transmitted by the discharges from the nostrils, mouths or bowels of these cattle, into the sewers of Chicago, there would be no question that the germs of anthrax might easily find a lodging in the people of Missouri with extremely fatal results. The germs of anthrax may not only be taken into the human system and produce disease by passing into the intestinal tract, but it is also susceptible of producing disease as the result of inoculation, so that a person bathing in water in which there were present germs of anthrax, if he had on his body any abrasions of the skin would be particularly liable to receive an infection from anthrax which might very probably end fatally.

It is not an uncommon thing for anthrax to be communicated to those who are handling the skin of animals and who may become scarred or bruised in the course of their occupation.

The germs of anthrax being practically indestructable under ordinary conditions, is frequently conveyed in hides and skins, and in the refuse from leather manufacturing establishments might easily get into the sewage of the City of Chicago as well as by way of the Stock Yards.

The people of the State of Missouri resident in the counties bordering upon the Mississippi River are largely engaged in stock raising, and in times of drouth, the Mississippi River is practically the only source of water for the stock so raised,

and it has come to my knowledge that in such times, this water is parted for many miles from the shores of the Mississippi River to be used by both stock and the human inhabitants of the country adjacent. Should the sewage of Chicago become infected with the germs of antharx, and should those germs be transmitted as they undoubtedly would be into the waters of the Mississippi if the Chicago Drainage Canal continues to discharge the sewage of Chicago into the Des Plaines and Illinois Rivers, at such times there would be great danger of the occurrence of an epidemic of anthrax, not only among the human inhabitants of the State of Missouri, but also among the lower animals using the water.

Anthrax is recognized as one of the worst of water-borne diseases with which we have to contend, for the reason that when once it becomes established in a community it may attack both man and beast, and its eradication can only be accomplished by the absolute destruction of the bodies of animals so infected.

It is able to live for long periods of time in the earth, and may thereby be communicated long after the death of the primarily infected animal to other animals grazing over the surface.

I may add further that the disease commonly known as glanders is also transmitted through water, and that it is not an uncommon disease among the stock of this country at the present time, and the discharge of the sewage of Chicago, which is at any time liable to be contaminated by glanders, into the Illinois River, is another source of danger to the inhabitants of Missouri.

In fact, as we look into the future and see the probable growth of Chicago, both in industries and in population, and the added probability of infection of its sewage due to the more general spread of infectious diseases, it seems to me that the danger impending over the citizens of Missouri as the result of the discharge of the sewage of Chicago through the Drainage Canal into the waters of the Illinois River is a most fearful menace to the life and welfare, not only of the citizens of Missouri but of the citizens of other cities below the mouth of the Illinois River leaving entirely out of consideration the question of typhoid fever."

You recall that as having been given in the course of your testimony?

A. I do.

Mr. Austrian: Just here I think it is only fair for the coun-

sel for the Government to state the purpose of reading that part of the testimony into the record.

Mr. Wilkerson: The question is put to the witness because we conceive, first, that it is proper cross-examination of the witness upon the matters with reference to which he has testified in this case. That the opinion which he has there expressed is a proper subject of comment to be made upon his testimony as a whole, in the case at bar.

In addition to that we conceive that, passing the question of proper cross-examination which I understand is not specifically pressed as an objection to the question, the testimony is unquestionably competent because it deals with an issue as to which a large amount of evidence has already been presented by the defendants in this hearing.

Mr. Austrian: Will you stipulate that so far as this testimony is concerned, that question and answer which you have read, the witness shall be considered your witness, we not objecting to the form of the question.

Mr. Wilkerson: No, I am not making him my witness.

Mr. Austrian: On that point.

Mr. Wilkerson: I do not know any rule of evidence by which testimony, if it is proper cross-examination, then I am entitled to use it for any purpose in the case.

Mr. Austrian: If you conceive it is proper cross-examination. Inasmuch as it does not tend to show his interest, and inasmuch as it does not tend to elucidate any question put to him on direct examination, I don't think it is proper cross-examination.

Mr. Wilkerson: I think it is. I do not care to argue it.

Mr. Austrian: To get the record right, you have no objection to my raising the objection at this time that it is not proper cross-examination.

Mr. Wilkerson: Nor at the hearing; you may raise it at the hearing.

Mr. Austrian: I did waive it.

Mr. Wilkerson: Because if it is not proper cross-examination, I am frank with you when I say I do not see that there is any way we can cure the matter at this hearing. If it is not cross-examination you may make the objection at the hearing.

Mr. Austrian: Very well.

Mr. Adcock: You suggested that specific objection should be made.

Mr. Wilkerson: I stipulate you may reserve the right to make at the hearing the objection this is not proper cross-ex-

amination. And I suppose you will give me the stipulation if it is proper as our own testimony and it should be held it is improper cross-examination, I may use it as my own testimony, if I see fit to do it at the hearing, without recalling the witness.

Mr. Austrian: Yes.

Mr. Wilkerson: You gave that as your best professional opinion upon that subject, did you, Mr. Williams?

A. I did.

Q. And it is your opinion, I assume?

A. With some slight modification due to the advances of science in the past ten years.

Q. But it is substantially correct?

A. Substantially.

Q. And I direct your attention to page 2472, to the following: "Q. Mr. Williams, assuming that an epidemic of Asiatic cholera should occur at the City of Chicago under existing conditions of sewerage in said city, and existing conditions in an open drainage canal, the Des Plaines, the Illinois and the Mississippi River, and the existing conditions with reference to the intake tower of the St. Louis Water Works, and the storage and distribution of the water from the chain of rocks to the consumers in the City of St. Louis, I will ask you as an expert on water supplies for cities and towns is it possible or probable that the germs of that disease might find their way into the intake tower of the St. Louis Water Works at the chain of rocks and thence to the consumer?

A. In the event of an epidemic of Asiatic cholera in Chicago under the conditions now existing in the waters between Chicago and the chain of rocks, through which the sewage of Chicago now flows, there is not only a possibility but a probability, and almost a certainty, that the germs of the disease would be communicated or transmitted to the water supply of the City of St. Louis and the consumers thereof.

Q. Now, Mr. Williams, what effect if any would the conveyance of Asiatic cholera germs have under those circumstances upon the people of the City of St. Louis?

A. It would undoubtedly lead to an outbreak of Asiatic cholera in the City of St. Louis."

You recall that, do you?

A. I do. Wait a minute; I do not specifically recall that answer, but I have no reason to doubt it as it is what I would have said under the circumstances exactly.

Q. You gave it as your professional opinion?

A. Being in the record, it is undoubtedly what I said. It is my opinion.

Q. You adhere to it?

A. I adhere to it, yes.

Q. I direct your attention to another portion of the same record beginning on page 2475 of the volume to which I have above referred.

"Q. Now, Mr. Williams, looking forward into the future and considering not this generation alone, but those that are to follow, and considering the relation of the filth and infection of the Chicago sewage to the water of the Mississippi River as it flows along the Missouri shore, I will ask you to state your views as an expert on public health matters, regarding the above mentioned conditions, considered as a broad practical proposition.

A. With regard to the effect on future generations of the discharge of Chicago sewage into the Illinois River and thence into the Mississippi River, and its effect upon the water of the Mississippi River, I would say that there is no question in my mind but that the problem before future generations is one of far more difficult solution than that which we face in the present.

A careful study of the relations existing between the flow of the rivers which contribute to the water flowing past the chain of rocks, and the prevalence of water borne diseases in the City of St. Louis among those of her citizens who are users of the public water supply has led me to the conclusion that at the present time the remarkable immunity from serious typhoid infection which the citizens of St. Louis have thus far experienced, although they have been using water which is unquestionably at the time of entering the intake considerably polluted, is due very largely to the character and amount of water contributed by the Missouri River.

I long ago learned to appreciate the importance from a sanitary standpoint of Missouri River mud. As the Missouri River enters the Mississippi River, the amount of silt in suspension in this water amounts oftentimes to over 1,200 parts in a million. A large portion of this silt is of such a nature as to be quite readily deposited as the water approaches a state of approximate quiescence, and such a vast quantity of depositing mineral matter mixed thoroughly throughout the water of the settling basins of the St. Louis Water Works cannot fail and analyses show that it has not failed to remove a very considerable percentage of the bacteria which are daily

brought into these settling basins in the water as it comes from the Mississippi River.

Laying aside the question for the moment of the possible increase of infectious matter in the water supplied through the intake at the chain of rocks due to the increased growth of the City of Chicago and the other populations upon the drainage area of the rivers which contribute to the St. Louis water supply, it is to be borne in mind as time goes on the history of the Mississippi River will become the history of every other stream upon whose borders the hand of man has rested, and that while the total quantity of water which that stream will deliver from year to year will remain about the same as now, the quantity of water which will be delivered in times of drouth will be decidedly less than heretofore, and that larger and larger portions of the discharge will be concentrated in a few floods. The result of this upon the waters mingling to form the supply of St. Louis will be that in the future, the Missouri River will show a greater diminution in the percentage which it represents of the flow past the city than will the waters derived from those other two streams upon which the hand of man has rested for so long a time, that comparatively small changes are to be anticipated in the future in the quantity of their low water run-offs. It will therefore follow that the amount of silt furnished by the Missouri River will be less and less sufficient to remove from the mixed water the number of disease germs which even now exist there, leaving alone the possibility, or probability and the certainty that the number of those germs will vastly increase as time goes on.

It therefore seems quite clear to me that any added pollution of the waters of the Illinois or the Mississippi River will have from year to year a greater and greater effect upon the healthfulness and quality of the water which will be delivered under circumstances similar to those now existing in the treatment of the water delivered to the citizens of St. Louis by their water works system, and when we consider that in the City of Chicago there is now a population representing about one-third of the total urban population upon the watersheds tributary to the Mississippi River at St. Louis, and probably representing more than one-sixth of all the population resident upon those water sheds, and that now no city in this portion of the United States, or indeed in any portion of it, has shown such remarkable and rapid growth both in population and in industries as Chicago, there can be no ques-

tion that in the future the menace to the health of St. Louis arising from the discharge into the Illinois River of the sewage of the Chicago Sanitary District will be a much more tremendous and impending danger to the citizens of Missouri living along the Mississippi River below the mouth of the Illinois, than exists at the present time, grave though the present condition be."

Do you recall that question and answer?

A. I do in general, yes.

Q. And you state the same with reference to it as you did with reference to the other questions and answers, as to your having given it as your professional opinion?

A. I gave it.

Q. And as to your present opinion as to its correctness?

A. I gave it as my professional opinion at that time, and I think it is substantially correct at the present time.

Q. Do you know what happened in that case?

A. I do.

Q. The bill was dismissed, wasn't it?

A. Without prejudice to either side.

Mr. Austrian: With leave to re-file, if the menace to the people of Missouri became imminent.

The Witness: Yes.

Mr. Wilkerson: I asked that question, so that it might not be necessary to put in the opinion. We can refer to it if we want to.

Mr. Austrian: Certainly.

Mr. Wilkerson: Q. The result of the litigation was, was it not, that St. Louis adopted a different method of treating its water supply?

A. Yes, instead of trying to preserve it in its natural purity, they adopted methods of purification.

Q. Of course the method which St. Louis adopted is one which could be used in Chicago or any other large city.

A. No, it is a materially different proposition. The conditions at St. Louis are peculiar and require a treatment suited to those conditions. It is like treating ague or treating smallpox; you treat them differently.

Q. That is it would make a difference in the kind of works?

A. In the method of procedure.

Q. In the method of procedure?

A. In the method of procedure.

Q. In this work which you did in the Missouri-Illinois case, did you come in contact with current meters?

A. I do not recall. I think there were some gaugings involved in the discussion.

Q. In estimating the time it would take germs to go from one place to another, were there any measurements made by current meters?

A. No, that was done by floats. Floats were put in at Robey street, and were actually traced down the river; the floats being followed by parties in boats, and the time taken from point to point.

Q. My understanding and recollection was that there was a specific mention in that litigation of the use of current meters, and that use was made of them on your side of the case for the purpose of measuring the velocity of the water and determining the rapidity with which germs get from one place to another?

A. They might have been used. I do not recollect that detail at present; but the fact was time of transmission was established by the time it took the floats to pass down the river, by actual observation.

I think that records of the discharge of the Illinois River and Des Plaines were introduced to show that these floats were sent down, not at flood time but at low water. And it is quite possible that use was made of those results to indicate the probability of the time being greater or less..

Q. Your recollection is not definite?

A. My recollection is not definite, but I think it is quite probable, in fact, I am sure there was some information furnished as to the flow of the streams at different seasons of the year, whether it was obtained from current meters or from discharges over the dam at La Grange and Kampsville; there were three, in fact, or four.

Q. What I was getting at is whether current meter observations were used in that case, and were taken and accepted as results which were entitled to credit by scientific men.

A. Oh, they would be within reasonable limits, certainly.

Q. Now in your direct examination you made mention of a service which you performed as engineer for the Detroit Water Board. Is that the correct name of that?

A. Board of Water Commissioners of the City of Detroit.

Q. And in that connection you made measurements in the Detroit River?

A. We made some current meter measurements in the Detroit River, yes.

Q. Just what was the purpose of the measurements?

A. The purpose of those measurements was to determine the locations of the main currents in the American channel, for the purpose of locating the intake for the water works. It was not primarily for the purpose of measuring discharge.

Q. How extensive were those measurements?

A. There was a considerable amount of work of measuring velocities and direction of current done. I don't recall now just how much time it covered; and there was a gauging of the American channel made through the ice during the winter of 1896 and 1897 or else 1897 and 1898, I guess.

Q. Were the measurements limited to the American channel?

A. The current meter work was limited to the American channel.

Q. What instruments did you use?

A. Used a Ritchie-Haskell Direction Current Meter.

Q. How did you rate the meter?

A. We did not rate it, because the question of the magnitude of the current was unimportant; it was simply the relative—wait a minute, I say we did not rate it. I would not be sure about that, either. For the bulk of our investigations we did not care about an accurate rating, and we took the maker's rating.

My recollection is not altogether clear, but I have in mind that the meter was rated in the canal at the water works, on second thought, by attachment to a boat and dragging along the side of the canal.

Q. This was not a piece of work which was of the same kind and magnitude as the work which has been under discussion in this case, was it?

A. No, there was no attempt made to make an accurate examination of the quantity of water passing. It was purely an approximate determination so far as the quantity was concerned. We cared very little about that. It was rather to find out how the currents were distributed.

Q. Was this rating a still water rating?

A. It was still water; any rating we made was still water.

Q. Was the ratio of velocities fairly stable at the different stations?

A. No, not at all.

Q. I think you said you did not aim at a very high degree of precision in this work?

A. Oh, no, we were not trying to measure the quantity of water?

Q. Did you make a report?

A. No, there was no formal report made. The results were reduced and an approximate measurement of the flow in the American channel was derived, which surprised us at the time on account of the smallness of it. We had supposed more water was going down that channel than appeared to be.

Q. You say this was to locate the intake?

A. It was with a view of locating the intake, yes.

Q. How did you finally locate it?

A. We finally gave up the current meter as being too difficult to operate and too deceptive in its indications for our purposes, and resorted to the thermophone, which is an instrument which records the temperature at the points where the instrument may be, and transmits it by means of a telephone, or something in the nature of a telephonic recorder, to the ear, and with that we made cross sections of the river from the water works well up into Lake St. Clair, and in the spring, of course, and summer—in the summer particularly, the colder water was coming from Lake Huron, and the warmer water from the shore, and the variations of temperature enabled us to locate quite fairly the position of the Lake Huron current.

In the winter, of course, the conditions were reversed, the shore water being the colder and the lake water the warmer; and we did some work late in the fall and early in the winter, but the bulk of the work was done in the summer.

Q. There was not anything in this work that involved what might be called a careful or critical study of current meter work, was there?

A. I think we got pretty thoroughly familiar with the idiosyncrasies of the instrument, and the difficulties which are encountered in current meter measurements.

Q. Was that the first time you had come in contact with those idiosyncrasies and difficulties?

A. That was the first work I did with the current meter.

Q. That was not your last current meter work, was it?

A. Hardly.

Q. You mentioned some work which you did in the Cornell Hydraulic Laboratory, did you not?

A. I think so.

Q. Do they have a canal there for the purpose of making this kind of obversations?

A. The Hydraulic Laboratory consists in part of a canal about 400 feet long, controlled by sluice gates at its upstream end, and having in normal condition two bulkheads across it, one about 75 feet from the inlet end, and the other at the lower end, where there is also provision for letting the water out through sluice gates.

The lower portion of the canal is equipped with a track, and a trolley is now operated on it electrically, which affords an opportunity for rating current meters or other instruments of that sort in still water, by simply filling the canal with water and closing the inlet gates.

Q. How large is the volume of flow in that canal?

A. When you are rating it is not anything, that is when it is closed. We have handled—

Q. I should have said at the different velocities at which the water flows. I want to get some idea of the size of that canal.

A. That canal is 16 feet wide and 10 feet deep at its upper end, and has a slope of 1 in 500; 1 foot in 500; so that the lower end is about 11 feet 4 inches deep, as I remember it. And water may be run through it at any depth from just enough to wet the soles of your feet to 10 feet.

Q. Take a depth of 10 feet, and with the weir conditions which you had there, how much water went through this canal?

A. We have handled very close to 500 cubic feet per second through that canal.

Q. Well, how does that compare with the quantity flowing through the Sanitary District Canal, through the diversion of 10,000 cubic feet? That would be about 2½ per cent. of it?

A. Oh, more than that.

Q. Five per cent.?

A. It bears about the same ratio to the water flowing through the Sanitary Canal that the water flowing through the Sanitary Canal bears to the water flowing out of the Great Lakes.

Mr. Austrian: That is, if the Sanitary Canal was running 10,000 cubic feet per second?

A. If the Sanitary Canal was running 10,000 cubic feet per second.

Mr. Wilkerson: Q. Which is 5 per cent. of 10,000 cubic feet per second; and of the water flowing out of the Great Lakes, say through the Niagara River, what per cent. would it be?

A. A quarter of one per cent., about ¼ of 1 per cent.

Q. You made some measurements in the St. Marys River?

A. We did.

Q. When and where were those made?

A. Those were made between Point Brush and Pointe Aux Pins, about six miles above the locks.

Q. For what purpose were those made?

A. They were made for the Michigan-Lake Superior Power Company, who were at that time interested in showing the effect of a diversion of water through their power canal upon the flow of the river, or upon something in the vicinity. I do not know that I am entirely clear as to just what their purpose was.

Q. You had some specific work in which you were engaged, some project?

A. These measurements were undertaken before the permit for the opening of the power canal was granted, if I remember correctly; and it was thought at that time, I think, that there might be some controversy in regard to the amount of water that could be diverted. At any rate the Lake Superior Power Company wished to either make, or pretend to make some measurements of the St. Mary's River at that point.

Q. I do not just understand that phrase "make or pretend to make." Was there any significance in the use of the word "pretend"?

A. Yes, there was.

Q. What was there?

A. The history of the Lake Superior Corporation shows that it was generally pretending to do things, and whether that it really meant to make those measurements or not, I am very much in doubt.

Q. You were not pretending, were you?

A. I was not.

Q. Was there anything that took place before you made the measurements that gave you the impression that you were just merely going there to go through the form of doing something, without regard to the accuracy of the results?

A. No, not at all; the precautions that were taken to insure accuracy were certainly such as I think would meet the criticisms of the representatives of the Lake Survey, at that time at least.

Q. What method did you use?

A. Well, meters were rated in the ordinary way in still

water by dragging from a truck in the laboratory in Cornell University. A provision was made for re-rating them in the Bay at Pointe Aux Pins, Wheeler Cove, for re-rating in Wheeler Cove, in a similar location to that used by the Government Engineers in the rating of their meters for the St. Marys River discharge; and various propositions were considered for handling the boat.

One contemplated stretching a cable across the channel, which I never could quite agree to, as I felt very sure that it would be, not an imaginary but a real obstruction to navigation, no matter how expertly the ends of it might be handled, when steamboats came down there with the frequency that they did. The work was finally done by shifting anchors.

Q. You are speaking of the gaging?

A. I am speaking now of the method by which what might be termed the co-efficient work was carried out, or rather the determination of index velocities—perhaps that is a more proper term—the establishment of the co-efficient. And we encountered very serious obstacles, which also must have been encountered in the work of the Lake Survey, although until recently there has been little mention of it, namely the effect of passing boats upon the distortion and disturbance of the vertical curve. We found that the vertical curve would be very greatly disturbed by passing boats, even though they were a considerable distance away.

I regret that I do not have with me the results of those observations, as there is some rather instructive information in there as to the effect of that sort of disturbance.

Q. You say the difficulty was on account of passing boats?

A. Yes, of steamers coming down. The water was about 50 feet deep there, and of course boats were then loading to about 18 or 19 feet.

Q. What year was that?

A. No, they were not loading as deeply as that because the lower channels in the St. Marys were not large enough. I hardly think they were loading more than 16 feet at that time.

Q. What year was that?

A. That was in 1900, I believe, or 1889. I will not be certain.

Q. After your Detroit measurements?

A. Yes, that was either 1899 or 1900.

Q. This difficulty arising from passing boats was a difficulty which was encountered in some of the earlier observations on the St. Clair?

A. I do not recall there was much said about it in the earlier reports. Latterly in some more recent ones, the matter has been treated.

Q. It was not encountered, was it, in the measurements that have been made by the Lake Survey in the Niagara and St. Marys?

A. No, it was not in the Niagara. It might have been in the St. Lawrence, though I do not know.

Q. I wish you would give us the particulars of the cross section which you selected for this work; the depth and other physical characteristics.

A. In my office I have the information that would enable me to give specifically what you are asking; but I can give you in general an idea what that cross section was.

Q. I will ask you to give it in general?

A. On the American Shore, there was for a distance of perhaps 500 feet more or less a shallow that I think at no point was more than 8 feet deep; running from that to practically nothing, and beyond that the channel deepened quite abruptly, and to a depth of in the neighborhood of 50 feet. Referring, for the purpose of refreshing my memory, to William's Exhibit 2 entitled "Chart 3 of the St. Marys River," the channel was about 1300 feet wide at this point, and the depth indicated on this chart is 53 feet, which coincides with my recollection of about the depth we had in the deepest portion of the section.

The total width of the river appears on the chart to be about 2400 feet.

Q. What was the speed of the current?

A. I don't recollect it at the present moment.

Q. Pretty slow water, was it?

A. No, that was moderately swift. I should say it was somewhere around three feet a second.

Q. Mean velocity?

A. I will not be sure. Of course the flow through the shallow portion was negative part of the time; it was flowing backward, so that that was treated separately.

Q. Was it exposed to wave action?

A. Not to any—at least at no time when I was there did the waves interfere. In the case of the wind in a certain direction, you might have, I would think, very considerable waves there, as there was quite a long—

Q. How much time were you there?

A. Oh, I was there probably a week.

Q. Out of how long?

A. Oh, they were working on the thing from about the beginning of August until cold weather, intermittently. I do not know that they were working continuously. A considerable part of the time was spent in preparation, getting things ready to work with, establishing ranges and all that sort of thing; and I rather think that they were not actually engaged in gaging operations, not more than a month, and in that time they probably were not on the river half the time.

Q. You were there that week during the month when they were making the observations?

A. No, I was there during the time they were making the preparations, laid out the scheme, and then did not go up again. I got weekly reports of the progress, and lack of it.

Q. Well, when there was an upstream wind, wasn't there difficulty in keeping the boat on the section line?

A. So far as the location of the boat on the section is concerned, that was controlled by ranges, and the boat was kept there within a comparatively narrow margin. As to the amount of difficulty they had doing it, I can't say, but the boat was manned with a number of oarsmen, in addition to the anchors.

It is quite possible that if the wind were blowing up-stream, it would have been more difficult to hold the boat in place.

Q. Did you use anchors?

A. We used two anchors ordinarily.

Q. To hold it when the wind was down-stream, as well as up-stream?

A. We used it wherever the anchors were needed.

Q. Now the result of your experience on the Detroit River has been such as to give you the opinion that these current meters ought not to be used when you wanted to get very accurate results out of them?

A. It gave me the opinion that we could do considerable better by the use of floats, wherever floats could be used. And we did make some runs on the St. Marys with floats, but on account of the extreme depth of the water, it was impossible to get a float that would measure the lower portion of the stream, so that the current meter was all you could use?

Q. So you reached the conclusion that that was the best method of making these measurements?

A. For that situation, yes.

Q. Where were your water gages located?

A. There was a gage located at Brush Point and across

the river at Foot's Dock, and the gage below at the head of the canal, maintained by the Government. The records were assumed to be available to us, so that we didn't attempt to put anything down below.

Q. You took the Government measurement as accurate?

A. We took the Government gage record at the Soo for anything we wanted below the section.

Q. And accepted that?

A. Oh, yes.

Mr. Adcock: Q. That was the gage record showing the elevation of the lake at the time?

A. The elevation of the water.

Mr. Wilkerson: Q. You superintended the work of combining these observations so as to reach a result, did you?

A. We never got far enough to reach a result.

Q. Did you attempt to reach a result?

A. No, because we never got clear across the river. All we did was the reduction of the individual verticals, the plotting of the observations.

Q. Why didn't you go across the river?

A. Well, it was partly on account of the difficulty of getting through the steamers, and partly for lack of satisfactory equipment for handling the apparatus. The difficulty of handling the thing from a row boat was very considerable, on account of the slowness with which you were able to move from place to place, and it was proposed to make use of a launch the following season. And the work was finally suspended with that understanding, so that we considered the work that we had done up to that time as of a preliminary nature, and indicating to us the difficulties we were likely to encounter.

Q. So the result of your work was that between August and November, you really failed to get any result as to the measurement of the river, was it?

A. That is correct; we did not make a complete gaging of the river except—let me see, the floats I think gave us information extending across the channel but I cannot be certain, because I have not looked at those results for several years. I do not remember now just to what extent they did go.

Q. You made no attempt to derive an increment?

A. Oh, no.

Q. Nor did you derive any equation of discharge?

A. No.

Mr. Adcock: Q. Was there any question of increment involved there?

A. No, there was no question of increment involved at the time. The question of lowering was not being considered at all. It was a question as to whether they had the right to take a certain amount of water.

Mr. Wilkerson: Q. You were measuring the quantity of water?

A. We started out to measure the quantity of water simply.

Q. Have you in mind a similar experience which the Deep Waterways Commission had on the St. Lawrence River?

A. I never was familiar with the work which the Deep Waterways Commission did on the St. Lawrence. It was my impression that they made no gagings there; whether they attempted it or not, I don't really know.

Q. I assume from what you have said, Mr. Williams, that your final conclusion was that the section which had been selected for this work was an impracticable one, wasn't it?

A. No, I should not say that. The passage of boats interfered very materially, and for satisfactory work there it would have been necessary to make the observations at times when boats were not passing. It would have had to have been done late in the fall, or times of fog.

Q. Or select a cross section some place else?

A. Well, you could not get a cross section in the St. Marys River, or it would be very difficult to get a cross section in the St. Marys River, where you would not have more or less trouble with passing boats.

Q. You could have obtained a better section than you had, couldn't you?

A. I rather doubt it. Of course at first sight, one would prefer the International Bridge.

Q. That is to say if you had a swifter velocity, a more compact section, you would expect better results?

A. Provided it was not too swift, provided there was not too much disturbance there.

Q. Von Schon measured a section above the bridge, didn't he?

A. Not that I know of.

Q. You are not familiar with that piece of work?

A. No.

Q. You said, not that you know of. Did you ever hear about it?

A. I have no recollection of it. This work, of course, was done by direction of Mr. Von Schon, as Chief Engineer of the Lake Superior Power Company.

Q. You do not know what he might have done on another occasion?

A. I do not know what he might have done on another occasion, but Mr. Von Schon had previously been in the service of the United States Engineer's Office, and whether he made any gagings at that time or not I could not say.

Q. You would not be surprised if it were a fact that he did pick out another section, and actually make final, definite measurements?

A. I would not be surprised if Mr. Von Schon made some further measurements. I think he did not, however, after this date.

Q. Do you know whether Mr. Von Schon ever made any hydraulic measurements for the United States Government?

A. I am not aware that he did. I am not particularly familiar with his experience while he was connected with the United States Engineer Office. I think Mr. Shenehon, who was a colleague of his in the office at the time, could give abundant information on that head.

Q. What I was trying to find out is: I understand it to be a fact, and I thought we could get it here, that after the time you embarked on this work, which was only partially completed, there was in fact another section which was measured, and the work was prosecuted through to a finality.

A. I think not. To the best of my knowledge and belief that is not the case.

Q. That is you mean by Von Schon?

A. Yes. The United States Engineers were measuring the discharge prior to this and afterwards, which measurements of course are of record. But I am speaking of the work done by the Lake Superior Power Company.

Q. You have spoken of the Detroit and the St. Marys Rivers. Are there any other rivers of that size, on which you have done any work?

A. Current meter work you mean?

Q. Yes.

A. Which I have personally done?

Q. With which you have had anything to do in the way of supervising the work, or being responsible for the results of the work?

A. No, I think not.

Q. So that as preparation for, and as a basis for your criticism of these engineers who have done successful work, you have never done any successful work yourself, have you, Mr. Williams?

Mr. Austrian: I object to the form of the question.

Mr. Wilkerson: That is a fair question.

Mr. Austrian: No, "These engineers who have done successful work" that is a matter of opinion.

Mr. Wilkerson: If the witness has done any work in which he has ever successfully measured a stream such as the ones under consideration in this case, I would like to have him state it.

Mr. Austrian: There is no objection to that question.

Mr. Wilkerson: All right.

The Witness: What is the question?

Q. (Question read.)

A. I have not, and I doubt if anybody else has.

Q. Your doubt is based upon your experience, isn't it?

Mr. Austrian: His doubt is based upon his conclusions.

A. No, my doubt is based upon the records of such observations by other people, as well as my own experience.

Whereupon a recess was taken to 3 o'clock p. m.

After Recess 3 p. m.

GARDNER S. WILLIAMS resumed the stand for further cross-examination by Mr. Wilkerson and testified as follows:

Last question and answer read as follows:

"Q. Your doubt is based upon your experience, isn't it? A. No, my doubt is based upon the records of such observations by other people, as well as my own experience."

Mr. Adcock: Q. Does that complete your answer to the question put?

A. Yes. I am entirely willing to strike out the last part of that answer if you want to. I think it is not responsive.

Mr. Wilkerson: Q. I think you said in your direct examination, Mr. Williams, that you had measured some small streams?

A. Yes.

Q. Which ones?

A. I measured the Huron River, that is to say I supervised the measurement of it. I never actively—

Q. What river is that?

A. Huron River, Michigan; the Tittabawassee River, and a number of other small streams that I have measured.

Q. Let's have some of them.

A. Fall Creek, or better say Six Mile Creek, Ithaca, New York, Taughannock Creek, near Ithaca. I can't think of the name that the stream went by in the northern part of the state, near Traverse City, a small stream; the Black River in Michigan; the Chippawa, Cedar, Pine. That is all I think of at the present moment.

Q. Please take them up in order and state as nearly as you can the volume of flow of each one of them, and mean flow.

A. The Huron River mean flow is about 400 cubic feet per second. The Six Mile Creek mean flow, I have forgotten what the mean flow of that stream is at the present moment. The minimum of the creek about 25 cubic feet per second, the maximum running it up to about 10,000 for a maximum.

Q. What were the measurements?

A. 10,000 on one measurement, and others in between. I think I measured it down as low as about 15 cubic feet a second, as I remember now.

Q. What river was that?

A. That is Six Mile Creek, near Ithaca, New York. I am not speaking of current meter measurement wholly. I do not want to be misunderstood as to that.

Q. I understood you did not use a current meter on an of these?

A. Oh, yes, I have used the current meter a good deal.

Q. Let us have the volume first; then we will get the detail of the measurements?

A. I can't recall those figures, Mr. Wilkerson. I will be very glad to supply them to the Commissioner and introduce them in the testimony.

I will say now I do not think there is a stream involved, whose average flow is over 2,000 feet a second. My memory is 1500 for the largest, but I will give you the actual average discharges.

Q. That is all right, unless you think you are able now to state them approximately.

A. I am not because I do not try to remember those things. I have a memorandum, but the only one I remember is Huron.

Q. You think no one has more than 2,000?

A. As an average discharge, there is nothing more than 2,000 cubic feet per second.

Q. Do you remember at this time the particulars of the work which was done with reference to the Huron River?

A. Oh, yes, the discharge of the Huron River has been measured various ways, by current meters, by floats, by the measuring of the head over dams, or measuring the water that went through wheels; that is using the water wheel. As a matter of fact it has been gaged all those ways, and finally for a very low flow we went so far as to gage the water that flowed over a dam, in barrels.

Q. In any one of the pieces of work you did on the Huron, did you use the current meter?

A. Oh, yes.

Q. How many times?

A. Several times. I don't remember exactly but we always had one around the office; used it more or less.

Q. What was the thing you were endeavoring to determine, the quantity of water?

A. The quantity of water passing.

Q. On which one of the other rivers that you have named did you use the current meter?

A. We used the current meter on the Black; used the current meter on the Tittabawassee, on the Chippewa. I don't know, we used it every little while as far as that goes, used it frequently.

Q. In your experience then in the measuring of these various streams and rivers, you have made use of the current meter as an instrument by which you thought you could arrive at a conclusion with reference to the volume of water flowing through the river?

A. Yes, and expect to continue to do so.

Q. And made reports with reference to each one of them, in which you gave your conclusions based upon observations taken with the current meter.

A. I frequently make reports in which I make use of current meter measurements as a basis of approximating the flow in the stream, yes. I won't say I have done it in all these cases, but I have in several of them.

Q. In your professional experience, you assume as one of the elements which has entered into the result which you have stated, that the current meter is a proper instrument to be used for that purpose?

A. Certainly.

Q. And that is not only your own experience, but it is that of engineers generally, is it not?

A. It is generally accepted as a proper instrument, and in many cases as the only instrument that can be used; under certain circumstances it is the only one that can be used.

Q. And in the great majority of cases, it is the best way, isn't it?

A. It is not the best way—

Q. The best practical way?

A. No, I would not say that. What I would say is this: That there are a large number of cases, and probably at least 75 per cent. of the cases, where you are called upon to measure the flow of water, where the current meter is the best means that can be applied. Where the channel is of such a nature as to permit of the use of floats, a more accurate measurement can I think be obtained, and oftentimes better results can be obtained by the combination of the two than could be obtained by either one alone.

Q. The use of the floats is subject to very considerable mathematical uncertainties, is it not?

A. Not so much as the use of the current meter. The float passing in a vertical plane down through the stream, you are quite assured that you have the mean velocity of the water from the surface to the bottom of that float represented by the velocity of that float. Now, the current meter to get that same information has to occupy sundry positions in the depth that is covered, so that the float is integrating the velocity through the area over which it travels.

Q. Can you use the float in measuring—

Mr. Austrian: Let him explain fully, in detail.

A. (Last answer read.) And when a number of floats are run down through a stream at various points in the cross section, each one of these floats covers points covered by the current meter in a vertical only it covers it more completely, as far as the length of the float goes. The difficulty with, or the limitation of the float lies in the fact that if the bottom be rough, the float has to be a considerable distance above the bottom to prevent its being stopped by the obstructions; and you also have to take into consideration a possible change in area of your cross section through the course that your float travels over, so that it means that you must have a channel of practically uniform section for a reasonable distance; that is one over which you can time the passage of the float, and without introducing large error in the time element.

The other limitation is that it is not ordinarily practicable to use floats in very deep water, for the reason you can't handle a float that must be weighted sufficiently to stand erect and have buoyancy enough to carry it down a large stream. I think that about 30 feet is about the limit of depth that any one has handled floats in, so far as I know; I mean vertical rod floats.

I have no particular confidence in the so-called double float. That is only a shade better than the surface float to my mind.

Mr. Adcock: Q. What is the double float?

A. The double float consists ordinarily of two balls, one of which drifts on the surface, and the other is connected to it by a chain or wire or string. and floats at some distance below the surface; and it is supposed in that way they would get some sort of a measure of the velocities below the surface.

The objection to that method is that there is no certainty as to where the lower ball is; it may be vertical under the upper one, or lagging behind or moving ahead; the cord may be inclined or curved; and it is practically impossible to tell what the lower one is doing.

Q. How is the float you have mentioned here constructed and used?

A. We ordinarily take a pole of dry wood and load it at the bottom. One way of doing it in the field is to load it with sheet lead, load sheet lead upon the bottom by wrapping it around the bottom until the float will stand erect in the water, with a small amount of the top exposed. Then this float is released in the current in a vertical position and floats with the current over a measured course, the time of travel being taken, and of course that measures the velocity through the range that it travels; and by putting in a series of floats across the river you get the same thing you attempt to get with your current meter by taking a series of verticals.

Mr. Wilkerson: Q. Does the water flow with the same velocity at the surface as it does down near the bottom?

A. No, it does not.

Q. What determines the rapidity with which the float moves down?

A. The average volicity of the water.

Q. Do you have to apply a mathematical correction to determine what the mean velocity is?

A. Not for the portion of the channel that is covered by the float itself. When you come to extend the discharge to the bottom of the stream, then in the lower portion of the stream

you must make a—some sort of a correction. You must either do as you do with the current meter sketch in the curve at the bottom, just as all these observations have been done, or you must adopt some mathematical method of computing it.

There has been devised a formula for application in that case, which I have tested in reasonably smooth channels and have found to give very accurate results, considerably better than we were able to get with the current meter. But when you come to apply it in a stream with a rough bottom, why it—

Q. Or a deep stream?

A. Or a deep stream, where you can't reach to the bottom, that lower portion of the curve must be investigated in some way.

Q. 30 feet is the limit?

A. I think 30 feet is as deep as any one has operated. And I would not like to be positive that that depth has been handled.

It is perhaps interesting in that connection to note that when the Haskell Current Meter was first put upon the market, its accuracy was established by a comparison with floats; and it was shown that they agreed, that the meter agreed with the floats within a small percentage. That statement was published in the catalog of the Ritchie Company, and in fact I think I saw it not long ago in print.

Q. By what process of reasoning do you reach the conclusion embodied in the statement which you make that the float travels at the mean velocity of the stream?

A. Because the observations which have been made on that head show that to be the case. That subject is investigated quite at length in the Lowell Hydraulic experiments by Mr. James B. Francis, published about 1855 I think. I think you will find it discussed in the first volume, I mean the first edition; and while it is theoretically possible to prove that the float will slide down hill, will slide down the water plane a little faster than the water moves, even that correction is one in fractions of a per cent., and experimental observations indicate that the float is measuring the water through which it passes with a more satisfactory degree of precision than I have been able to get out of any current meter work that I have known of.

Q. Is it not a fact that Mr. Francis has reached the conclusion that the current meter travels at a mean velocity, by a mathematical deduction?

A. He reached the conclusion that the float would theoretically travel faster than the water, by a mathematical deduction.

Q. Then he devised the formula by which it was to be corrected?

A. No, he did not. His formula was based upon his experiments. He measured the quantity of water flowing in channels with floats, and compared it with the measurement of water flowing over a weir, and by using floats of different lengths he was able to determine an expression for the correction to be applied to cover that portion of the stream which the float does not actually traverse, if you choose to make that computation mathematical. If you do as in the current meter measurements simply plot your curve and draw your curve in, you do not need any mathematical computation. Then it becomes a matter of experience to draw that somewhere near where it ought to be.

Q. Do you know how many days Mr. Francis covered in his observations, which were used as the basis for this conclusion which you have just stated?

A. I do not. A portion of his work is published in the Lowell Hydraulic Experiments. Whether it is all there, I am unable to say. But independent of Mr. Francis, I caused a series of investigations to be made at Cornell upon the same subject, and in that we spent—oh, we were working on it parts of two years. We worked almost continuously on it for pretty nearly a month, and from those results we found that our float gagings ordinarily checked the weirs within about 1½ per cent., 1½ to 2. At the same time, the current meters were checking within from 3 to 4, ordinarily.

Q. These observations as to which you have just testified were made in this 16 foot channel which you mentioned this morning, weren't they?

A. Those at Cornell, yes.

Q. And at Lowell they were measured in a canal?

A. They were measured in a canal there, the width of which I do not remember positively. I have in mind that it was somewhere in the neighborhood of 50 feet in width, but I am speaking solely—

Q. Do you know the range of velocities which was covered by the floats in either one of the two sets of measurements about which you have testified? Have you got the figures in mind at the present time?

A. I haven't the figures in mind at the present time. At Cornell, let me see—I do not want to say; I thought I could

tell but I can't. My guess at the present moment would be that we did not go over 5 feet.

Mr. Adcock: That is 5 feet a second?

A. Five feet a second.

Mr. Wilkerson: At Lowell, was it any more than that?

A. I think not.

Q. Was it much less than that?

A. My recollection now of the Lowell experiments is they were around 2 feet. Is that your recollection, Mr. Shenehon?

Mr. Shenehon: That is my recollection.

The Witness: That is as I recall it. That is a matter that can be looked up.

Mr. Wilkerson: You and Mr. Shenehon are agreed?

The Witness: If Mr. Shenehon has looked them up within a few days, I will take his word.

Mr. Shenehon: No, I have not.

Mr. Wilkerson: Let me ask you this question: Is it not a fact that the data which are at hand relating to the measurement of streams by floats are comparatively meager and are in small streams compared with the ones on which the data in this case were taken?

A. Well, floats were used quite extensively on the Mississippi River of, I think all types. In general however the float measurement is not used for the reason that it requires a large party to operate; that is you cannot handle float measurements in a stream of any size without a party of three or four times the men that are necessary for current meter measurement.

Q. So that comparatively speaking, the data available with reference to the use of floats would properly be said to be meager?

A. Well, it depends a little bit on just what you mean by meager. The floats have been compared with the number of gagings made by current meters, I think within the past 20 years have been at least 1 to 10; that is, there have been at least ten meter gagings to one float gaging.

Q. So that it is fair to say that the current meter is the generally accepted instrument to use?

A. Oh, no question about that; it is the instrument ordinarily used for this purpose.

Q. It has been your experience that the results have been correct within 3 or 4 per cent.?

A. No, I would not say that.

Q. I understood you to say that?

A. No; where under exceptional conditions we were check-

ing them against the weir, at Cornell, we were able to get within sometimes as close as 2 per cent. of the weir, but the conditions there were extremely favorable. There was no question as to the character of the section, as to the area. The bottom and sides were smooth, so that it was possible to get the current meted down very close to the bottom, closer than is possible in ordinary streams; and the velocities were screened and smoothed out, so as to give quite regular flow, so that the conditions there it seems to me would be more favorable than ordinary field measurements.

Q. Is that the only place where you had an opportunity to check absolutely the accuracy of current meter measurements, where you had the opportunity of measuring the quantity of water passing over the weir?

A. No, we had a case recently for the Sanitary District, in connection with the test of some pumps at Wilmette, where the water delivered to the pumps was measured by current meters, and the water after passing the pumps was measured over a weir. We had an opportunity to check there.

Mr. Adcock: Did I understand you to say the Ritchie Company, the manufacturer of these current meters that have been used by the United States Lake Survey, in their catalog representing the value of their meter, and so forth, the accuracy of the meter, state that they approach or are designed to approach the accuracy of floats?

A. They show a comparison in there of discharge measurements, by float and meter, and show how closely the meter checks the measurements by floats.

Q. Do I understand that they consider the float as the most accurate measurement?

A. Apparently, as the generally accepted method at that time. Bear in mind that was—

Mr. Wilkerson: This was a statement in a catalog 20 years ago, is that it?

A. No, this was a statement that applied to the time the Ritchie-Haskell Meter was invented. When was that, 1880 or 1890?

Q. At least 20 years ago.

A. As I say, it is 20 years ago.

Q. It was a statement in a catalog 20 years ago?

A. No, I saw that statement, I received that catalog considerably less than 20 years ago. But the point I am getting at is this—

Q. Some old statement, like most catalogs, they continue from year to year?

A. No, let me explain: At the time the Haskell meter came into use, the float was recognized as a standard method.

Q. That was the only method before they invented the meter?

A. That was really the—that was the only method of reasonable accuracy that was available for field measurements on a large scale, up to the time the current meters were introduced, and naturally the comparison was made with them.

Now, my purpose in referring to them was simply to call attention to the fact that at the time the current meter was introduced, the float was recognized as a standard method. Now it has been superseded by the current meter on account of the greater ease with which the observations can be made, not on account of greater accuracy, except in cases where it would be, you might say, practically impossible to measure with a float, on account of the depth or irregularity of currents.

Q. In these Sanitary District measurements which you have testified about as being made at Wilmette, what was the velocity of the water which was being measured?

A. I think the average velocity was about 4 feet a second.

Q. What was the volume?

A. It was around 280 cubic feet a second.

Q. Just one more question about this catalog statement to which Mr. Adcock has made reference: I will ask you whether you remember whether the float which was used as a check against the accuracy of the current meter measurement was a surface float or a sub-surface float?

A. Rod float.

Q. How deep?

A. I don't recall now.

Mr. Adcock: When you speak of the rod float, it is the float that you described a little while ago?

A. As a rod floating vertically in the water.

Mr. Wilkerson: But not reaching close to the bottom?

A. At Cornell University, we used floats with an immersion of 98 per cent. That is to say, we got within 2 per cent. of the bottom of the channel.

Q. You had a smooth bottom?

A. Yes, we had. That is why I say our deductions there established the fact that the float moves with the mean velocity of the water through which it travels, because we covered something over 90 per cent. of the cross-section of the channel with the float; that is taking both the variation from the sides and the bottom.

Q. There are not many cross-sections you can get that way, in measuring actual streams?

A. That is what I say.

Q. That is why we use the current meter instead of the float usually?

A. That is one reason why.

Q. As a matter of fact, Mr. Williams, there is no use in talking about using a float to measure the rivers that we have been discussing in this case, whatever may be said about small canals or small creeks or little rivers? You cannot use a float to get the measurements to refer anything to, in the kind of rivers we are discussing in this case, can you?

A. I think they would have gotten more accurate results if they used floats to cover as much as they could, and leave the current meter to take care of the bottom, where they could not reach it.

Q. But they did not?

A. They did not. You asked whether they could.

Q. As a matter of fact it has never been done successfully?

Mr. Austrian: Where?

Mr. Wilkerson: In large rivers; the size of the rivers connecting the Great Lakes.

A. There has been a good deal of that work done on the Mississippi River. How successful they regard it is more or less a question. It all comes to a question of relative precision.

Q. What is your opinion as an engineer as to the degree of precision with which the flow in the Mississippi was measured by floats?

A. I am not in a position to express an opinion in regard to the rod float work that has been done on the Mississippi River, as I have never studied the details of it. As I said a short time ago, so far as the double float work is concerned, I consider it practically worthless. But that is another proposition. The float measurements usually criticised on the Mississippi River are those double-float measurements.

Q. You know nothing about the rod floats?

A. I have never examined any records of the rod float gagings, and am not ready to speak of it.

Q. Do you know how engineers generally regard it?

A. Those with whom I had discussed the matter, who had experience with both the current meter and the rod float expressed a preference for the rod float wherever they could use it.

Q. Who did express that?

A. I think at this moment of George Y. Wisner.

Q. Anybody else?

A. I think that is the only one I happened to discuss the subject with.

Q. In connection with what river?

A. We were speaking generally, wherever you could use the float. The float was to be preferred to the current meter but there are a good many places where you could not use it at all, and there were other places extremely inconvenient or expensive.

Q. When was that opinion expressed?

A. That was expressed about 1899 or 1900. It was during the work at Cornell when we were experimenting with floats for the Board of Engineers on Deep Waterways.

Q. He had a good deal to do, didn't he, with the measurements made in connection with the compensating works on Lake Erie?

A. He was a member of the Board of Engineers, the Deep Waterways Commission.

Q. They did not use any rod floats there?

A. No, because it was not a suitable place to use them, for one reason.

Q. He used the current meter?

A. Yes.

Q. And he treated the current meter measurement as entitled to scientific credit, didn't he?

A. He always was very critical—

Q. I am speaking about his published reports?

A. All right, then his published reports speak for themselves. If you are asking me what Mr. Wisner thought about it, that is another matter.

Q. We haven't any way of knowing what he thought except through the reports.

Mr. Austrian: He may have expressed himself.

Mr. Wilkerson: We have his expression in the published reports.

Mr. Austrian: That may not have been his entire expression.

Mr. Adcock: Did he ever express himself to you in regard to the matter?

A. I do not know whether there is to be anything gained by going into that. I will say this in answer to Mr. Wilkerson's question, that Mr. Wisner—that the Board of Engineers on Deep Waterways made use of the current meter at Niagara as the most available means of measuring the flow of Niagara,

and they used it—and being the only information, and the best information, they based their conclusions upon it. I know however that Mr. Wisner, up to the time even of his death, was always skeptical of those Niagara measurements. I talked with him about that only a short time before he died.

Mr. Wilkerson: You do not recall any published documents, in which he said he lacked faith in them?

A. I think not. In the report of the commission, of course nothing of that kind would have been in good form, or permitted, perhaps, by the other members of the commission.

Q. He undoubtedly would have given expression to his real professional opinion in any report which he made?

A. I do not think that that thing got to the point of a professional opinion. I say he was suspicious of those records but they were the best that he had and he used them.

Q. In what years were those measurements made?

A. I say I discussed that matter with him a very short time before he died.

Q. In what year?

A. He died in 1905, 1905 or '06 somewhere around there.

Q. You say you made some measurements on the St. Lawrence River?

Mr. Adcock: Were you going to go into that question? You asked him about the measurements for the Sanitary District of Chicago. As you have referred to it, I think it only fair that he explain his connection with that matter and the results of the measurements.

Mr. Wilkerson: I think he covered that.

Mr. Adcock: No.

Mr. Wilkerson: If there is anything further that is proper, I am entirely willing to have him state it.

Mr. Adcock: And the results of his experiments there, in connection with it, because as it stands now it is merely referred to. You may draw deductions and so forth that may or may not be proper.

Mr. Wilkerson: Is there anything about that, Mr. Williams —I think you answered my question.

A. I did, I answered the questions you asked me. I think all you asked me was if I had compared current meters with weirs anywhere else than at Cornell. I mentioned that case; gave the volume.

Q. I asked you about the size, the volume of water that was measured and the velocity, and we had some such discussion here.

A. Yes.

Q. The effect of which was that was hardly a proper kind of stream with which to make an appropriate comparison?

A. (No response.)

Q. Now about the measurements which you made on the St. Lawrence River, when were they made?

A. The measurements on the St. Lawrence were made in, I think, about 1909 or 1910. I will give you the dates if you allow me to go upstairs.

Q. We can have them approximately; I do not care for the exact dates.

A. I will say about 1910. I will not be certain as to the year without looking it up. Time has been passing pretty rapidly since I got into this case.

Q. For what purposes were they made?

A. They were made to determine the flow of the St. Lawrence River, in connection with the proposed power development in the Couteau and Cedar Rapids.

Q. Did you measure the full flow of the river?

A. Yes. Don't misunderstand me; you say "Did I"? I didn't do the measurement myself. I advised in regard to the measurement, and recommended the parties who were engaged to do the work. The results were submitted to me and examined by me and criticised and were made use of in connection with some further work in connection with the power development; but I was not present during the gaging.

Q. Who was selected to make the measurements?

A. Mr. Murray Blanchard.

Q. Who is he?

A. He had charge of the gagings on the St. Clair, during 1902, wasn't it, Mr. Shenehon?

Mr. Shenehon: He was under Sabin.

The Witness: He had charge of them the last year according to Mr. Haskell's testimony. I am quite sure the last year's work that was done under Mr. Haskell, prior to 1908, was done by Blanchard as Chief of the party. And he then came down and had charge of the Detroit measurements. Let me settle that, because I do not want anything wrong in here. I am speaking from recollection of Mr. Haskell's testimony. (Referring to same.)

On page 51 of the continuously paged record, the question is asked: "Who was in charge of the work there?" the reference being to the St. Clair. "A. Mr. L. C. Sabin for the first two seasons, and Mr. Murray Blanchard for the third season. Q. Were they competent men for that work? A. They were."

Mr. Wilkerson: Was he hired on your recommendation?

A. He was.

Q. What method was used in measuring the flow of the river?

A. The ordinary methods of the United States Lake Survey.

Q. Used with your approval?

A. They were.

Q. Were water gages used?

A. Yes.

Q. How were the readings taken?

A. By observers at regular intervals during the observations. They did not use recording gages if I remember rightly.

Q. Were current meters used?

A. Current meters were used.

Q. What kind?

A. Haskell, and a Price.

Q. How were they rated?

A. Rated in still water by dragging in the usual manner, the procedure being similar in every respect to that adopted by the United States Lake Survey, which was then and is now regarded as the best practice in current meter work.

Q. Was there a law of discharge established as the result of those measurements?

A. There was not. The purpose of the measurements was to determine what correction should be applied to the gagings of the Lake Survey to make them applicable to the St. Lawrence in the location where the work was done, that being a considerable distance further down the river; and it was desirable to know how much greater or less the flow of the river at that point was than was indicated by the gagings at Waddington by the United States Lake Survey.

Q. For that purpose, you accepted the report of the Lake Survey at that point as accurate?

A. We accepted it as relatively accurate, yes.

Q. Did you make any report which was based upon the work of the Lake Survey as supplemented by your own work?

A. No, there was no written report made. We appeared in court, or rather appeared at a hearing before the Prime Minister and his Cabinet.

Q. And gave testimony?

A. And gave some testimony in regard to it. That is, we did not as a matter of fact give the testimony; we appeared but the testimony was given by others, and Mr. Noble and myself, who were interested in the matter, were not called upon to participate.

Q. You and Mr. Noble were on the same side of the case, were you?

A. We were.

Q. At that time you both agreed as to the manner in which the observations on the St. Lawrence were to be viewed?

A. That particular question did not come up at all. They were the best information we had as to the discharge of the St. Lawrence.

Q. You did not suggest there any necessity of recomputing the work of the Lake Survey by any methods of weighting the measurements, did you?

A. No, the matter of 10,000 cubic a second more or less was not of any particular consequence in that case.

Q. Well, did you suggest the necessity of rejecting any observations?

A. We did not discuss those observations at all.

Q. You just simply took the work of the Lake Survey as accurate for the purpose for which it was to be used?

A. We did.

Q. That was in a lawsuit—

A. Except to this extent: That we investigated to see what the difference was at our section over what was indicated at theirs.

Q. But in the work of the Lake Survey at that point, the gage elevation was used for the time of measurement and not for 24 hours prior, or a period of several days prior?

A. The question of gage elevation did not enter. We simply took the results as the United States Lake Survey had published them, and accepted them as being sufficient for our purposes. As I say, the matter of 10,000 cubic feet per second was of small consequence there.

Q. That is to say for the purpose of that case, it would not have made any difference whether the flow was determined accurately within 10,000 cubic feet?

A. It would not, no.

Q. Within what degree of accuracy were you interested in the result?

A. Well, we were contemplating on leaving somewhere between 40,000 and 60,000 cubic feet for the uses of navigation, as I remember it; 20,000 was sufficient for all they really would need, and we were going to leave them a large surplus, so that the question whether it was 10,000 feet more or less in that particular case had very little bearing. That is all there is to it. We made these measurements of our own to be sure, or to be able to say that we had measured it, or that the river had

been measured at this locality and that it was so and so, and we compared those measurements with the measurements by the United States Engineers. The gagings on the St. Lawrence referred to were made in 1909.

Q. I referred this morning, Mr. Williams, to some of these engineers who had done work and had reached conclusions on this subject involved in this case, in connection with their position on the International Waterways Commission and the Deep Waterways Commission and the Lake Survey. I direct your attention particularly to Mr. C. B. Stewart. What do you know about his work?

A. Mr. Stewart was in charge of or connected with the gagings on the Niagara for the Board of Engineers on Deep Waterways.

Q. Do you know anything about his hydraulic investigations at Wisconsin University?

A. Mr. Stewart has been engaged on hydraulic investigations at Wisconsin for some years back. I have received bulletins concerning the investigations from time to time.

Q. What is his standing as an engineer?

A. I am hardly qualified to say, as I have not followed his work closely and I do not know that I have ever discussed his work with anybody. I should regard Mr. Stewart as a very capable investigator.

Q. What do you know about the work of Mr. E. E. Haskell?

A. Mr. Haskell is recognized as an authority on current meter work; particularly on river hydraulics; had a long experience with the Government in the United States Lake Survey; and also has been engaged on hydraulic work for the Government in various capacities, on the Mississippi River Commission and with the Coast and Geodetic Survey; and was connected with the measurements of the Gulf Stream a number of years ago. And then he was Principal Assistant Engineer in charge of the Lake Survey; now Dean and Director of the College of Civil Engineering at Cornell, and a member of the International Waterways Commission.

Q. Is he in charge of the Hydraulic Laboratory at Cornell?

A. The Hydraulic Laboratory at Cornell University is attached to the College of Civil Engineering, and as Director, he of course has control of the laboratory. I think Professor E. W. Schoder is recognized as the engineer in charge, being of course under Mr. Haskell, so far as the supervision of the head of the department is concerned?

Q. What chair does he hold there, what is his title?

A. Who, Mr. Haskell?

Q. Yes?

A. I think he is Professor of Hydraulic Engineering. I do not remember what else.

Mr. Shenehon: Experimental hydraulics.

The Witness: I do not recall ever having noticed what the title actually was.

Mr. Wilkerson: He has had a very extensive experience, has he not, in water measurements?

A. He has done a great deal of it.

Q. He has had to do with water measurements on a large scale?

A. Yes, he is one of the leading authorities on the subject. There is nothing that I can say that would be too high commendation of Mr. Haskell's attainments.

Q. And in your opinion as an engineer, any conclusion which he might reach as to a fact concerning water measurements is entitled to great weight?

A. It would be. I should hesitate very much to question a conclusion at which he arrived until I had made a very thorough investigation of the facts on which it was based.

Q. Even then, would the fact that Mr. Haskell had reached one conclusion and you reached another, cause you to pause?

A. It would, until I had checked my work and satisfied myself that my conclusions were correct.

Q. Of course, as a matter of fact, Mr. Haskell in the measurement of large streams has had actually more variety of experiences and a more extended experience than you have had, has he not?

A. Yes, sir, that is entirely correct.

Q. And also in handling the observations which have been made, and in drawing conclusions from them, he has had a long record of work in that line, has he not?

A. He has a long record of work in that line, yes, sir.

Q. He is regarded as accurate, painstaking and very thorough, isn't he?

A. Very.

Q. Mr. Williams, you are also familiar with the work of Mr. Sabin, are you not?

A. I am. Mr. Sabin and I were college mates. We began our professional lives together, roomed together on our first job, and have had a very intimate acquaintance ever since.

Q. He has had long experience in connection with measurements of this kind?

A. I think he was the pioneer in those measurements of the later date.

Q. He had to do with the measurements on the St. Clair River?

A. He made the original measurements on the St. Clair River.

Q. He was Secretary of the International Waterways Commission?

A. Yes, sir.

Q. He built the Soo Lock?

A. He is building it.

Q. Building it?

A. The new lock.

Q. He has had as wide, if not a wider experience, in measuring water in the large streams than Mr. Haskell, has he not?

A. Well, that is more or less of an open question.

Q. Well, they are pretty well up?

A. Let me explain: The work of Mr. Sabin was all done under the direction of Mr. Haskell. Mr. Haskell before that time went through the elementary steps of stream gaging and got to the point where he no longer went out and listened to the tick of the meter, or read the register; and Mr. Sabin had immediate charge of the St. Clair measurements, and in my judgment he did a very excellent piece of work.

Considering that he had no previous experience; that there had not been two or three years of stream gaging going on in the development before he took hold of it, he I think handled that work and got results which are highly creditable to him. Mr. Sabin had had some experience in hydraulic work on the St. Mary's River, but the conditions there were quite different from those that were encountered on the St. Clair.

Q. Have you before you the report of the International Waterways Commission for the year 1910?

A. Yes, sir.

Q. I wish you would turn to page 10 of that report, paragraph 7. I call your attention to the following statement: "Actual values assigned to rainfall and evaporation are not well determined and cannot be used. It is of relative value and it has elements which it is necessary to know, and that value is found in the discharge measurements." In your opinion as an engineer is that opinion true or untrue?

A. So far as the statement that they cannot be used is

concerned, it is incorrect. So far as the statement that they are not well determined is concerned, it is in a measure correct, depending upon what you consider as the limitation of "well determined." Concerning the statement that the value is found in the discharge measurements, I would raise the question that it would be found there if the discharge measurements were accurate. If they are not accurate, then it is not found there.

Q. And the relative value of the elements which it is necessary to know would be in proportion to the percentage of accuracy of the observations, is that your opinion?

Mr. Austrian: Necessary to know for what purpose?

Mr. Wilkerson: To determine the water levels.

A. My answer is no.

Q. Well, would it have any relation to the degree of accuracy of the observations?

A. Not necessarily. There might for example be some condition that it was absolutely necessary to have, and still you might know nothing about it; and I think there are some such conditions involved in the problem that we are dealing with.

Q. That opinion is the opinion of Mr. Haskell, is it not?

A. I don't know whether it is or not.

Q. His name is signed to this report?

A. I see Mr. Clinton's name signed to that report also. Mr. Clinton is a distinguished attorney, whose principal practice has been in maritime law.

Q. And you think that Mr. Haskell's name to that report is entitled to no more weight upon an engineering proposition than the opinion of Mr. Clinton?

A. I think that it may be questioned whether Mr. Haskell would state that proposition in exactly those words; and if he does not state it in exactly those words, it does not mean exactly what it does here. The general interpretation that would be put upon that by a casual reading would undoubtedly be subscribed to by Mr. Haskell, and as a matter of casual reading I would subscribe to it myself. But where we come to specifically consider the meaning of the words involved, I do not agree with it—I would not say what anybody else would do.

Q. I direct your attention to page 84 of that report of the International Waterways Commission and ask you whether you observe the name there, "E. E. Haskell, member American Section?"

A. I do.

Q. That is signed to a document which is entitled "Appendix," which commences on page 23 of the volume in which that report appears?

A. Yes, sir.

Q. Now I direct your attention to page 76 of the Appendix, signed by Mr. Haskell. You have no doubt, have you, that Mr. Haskell intended to certify as an engineer that in his opinion the diversion of 10,000 cubic feet of water would result in a lowering of the level of Lake Erie of 5¾ inches, have you?

A. Mr. Haskell, testifying in this case, at a date not far different from that at which this report was signed, and saying under oath that the lowering of Lake Erie in inches by the diversion of 4,000 cubic feet per second at Chicago would be two inches, which statement appears on page 56 of the continuously paged record, and saying later in his testimony that the same proportion would apply—or saying in answer to a subsequent question that the same proportion would apply on 5,000, 6,000 or 10,000, and a diversion of 10,000 cubic feet per second on this basis representing 5 inches, I am somewhat in doubt as to whether he meant to say that a diversion of 10,000 cubic feet would represent 5¾ inches when he signed this report.

Q. From both the report and the testimony, you have no doubt he would fix that figure at five inches, have you?

A. In his testimony he did fix it at five inches, and I assume that he did it knowingly.

Mr. Austrian: On the same basis, in the report he fixed it at 5¾ inches, and you must assume that he did it knowingly?

A. Allow me to say in justice to Mr. Haskell, that Mr. Haskell's testimony was taken on February 17, 1909, and this report is dated December 4, 1909, so that he may have changed his mind in the interim.

Mr. Wilkerson: To the extent of ¾ of an inch?

A. Yes.

Q. Isn't it pretty clear to you Mr. Williams that his statement in his testimony about the two inches is a good deal like some of your statements, an approximate statement of the effect in round figures, as nearly as possible?

A. I think that Mr. Haskell would be very careful about making any other statements.

Q. You have spoken about Mr. Haskell and Mr. Sabin and their work in connection with these measurements. What do

you know about the work of Mr. Shenehon? You are familiar with his experience, are you not?

A. I am to a considerable extent.

Q. I want to know whether you are familiar with the extent of the work he has done in this case?

A. I think I am. Mr. Shenehon was connected with the United States Lake Survey and the United States Engineer Office for many years; was intrusted with responsible charge of important work at various times, particularly with the Niagara and St. Lawrence gagings. On the resignation of Mr. Haskell from the Lake Survey to accept the position of Director and Dean of the College of Civil Engineering, Cornell University, Mr. Shenehon then became his successor as Principal Assistant in the United States Lake Survey; and I have frequently expressed my regret that circumstances were not such as would have made it desirable for Mr. Shenehon to remain in the service of the Lake Survey Office.

He was called to a position at his alma mater as Dean of the Department of Engineering, or College of Engineering, for which position I had the pleasure of giving my most cordial endorsement as to his qualifications.

Q. He had to do with work on the St. Lawrence River?

A. He had been engaged on the St. Lawrence River. I am not familiar with the detail of his work there, though from his superiors I had heard very commendatory reports of his performance of such duties as had been left to his execution.

Q. And in connection with the investigation relating to the preservation of Niagara Falls, what do you know about that?

A. That was one of his pieces of work in connection with the Lake Survey.

Q. And the measurements of the Niagara River?

A. And the measurements of the Niagara River, than which, I say again, there is not on record a more carefully conducted series of investigations in natural science.

Adjourned to Saturday, July 19th, 9:45 a. m.

Saturday, July 19, 1913, 9:45 a. m.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Mr. Wilkerson: On yesterday, I directed your attention to a statement appearing on page 10 of the report of the International Waterways Commission for the year 1910, relating to the values to be assigned to rainfall and evaporation. And I called your attention to the fact that that report was signed by Mr. E. E. Haskell. In the answer which you made to the question that I put to you on yesterday, did you have in mind the following testimony given by Mr. Haskell in this case on the 16th of February, 1909, on page 67 of the deposition as filed in this case? I read: "I want to ask your opinion regarding the propriety of using any existing data in regard to evaporation, in the attempt to detect the presence or absence of the effect already produced on the lakes, by the diversion made at Chicago since 1909."

A. Are you sure about that paging. I have the reference all right, but according to my notes that is page 53. Is the paging the paging of the continuous record?

Mr. Adcock: You better follow that.

The Witness: I have referred everything here to the continuous paging.

Mr. Wilkerson: I will state parenthetically the portion of the testimony now referred to appears on page 67 of the deposition as filed in the case, and on page 53 of the record as it has been made up and paged continuously. "A. It is hardly permissible to use that data at the present time. Have you any knowledge as to how large the errors in those figures would be? Mr. Williams (Counsel for the District): I object to the question on the ground it is manifestly beyond the range of human knowledge to know, if they are not worthy, how unworthy they are. A. Do you wish me to answer? Q. Certainly. A. I should think one might easily get into an error of 20 to 25 per cent. Q. Now, the same question in regard to the precipitation, on the drainage of the Great Lakes? A. Precipitation is a great deal better known. I think it is safe to say that the observations of the Weather Bureau is given within 12 to 15 per cent., that is particularly the observations made during the later years."

My question is, did you have that in mind when you answered that on yesterday?

A. I would like to have the question that was asked yesterday and the answer read. I do not recall just what I did have in mind.

(Question and answer requested by the witness were read as follows: "Q. And you think that Mr. Haskell's name to that report is entitled to no more weight upon an engineering proposition than the opinion of Mr. Clinton? A. I think that it may be questioned whether Mr. Haskell would state that proposition in exactly those words; and if he does not state it in exactly those words it does not mean exactly what it does here. The general interpretation that would be put upon that by a casual reading, would undoubtedly be subscribed to by Mr. Haskell, and as a matter of casual reading I would subscribe to it myself. But where we come to specifically consider the meaning of the words involved, I do not agree with it—I would not say what anybody else would do.")

The Witness: I had in mind Mr. Haskell's testimony.

Q. I direct your attention to a chart marked in this case: "Haskell's Exhibit 1 for Identification 2/17/09," and to your testimony on yesterday in which your attention was directed to the statement on page 76 of the report of the International Waterways Commission concerning the effect of the diversion of 10,000 cubic feet of water per second upon the level of Lake Erie, and ask you whether or not in the answers which you made relating to that subject you had in mind the testimony of Mr. Haskell appearing in the deposition to which I have above referred, beginning on page 82, and in the continuously paged record page 63, as follows:

"Q. And your testimony is based upon the computations made by you from the plate which you hold in your hand? A. Yes. Q. And used by the International Waterways Commission? A. Yes. Mr. Williams: Now I would like to have that plate marked as Haskell's Exhibit for Identification and attached to the deposition so we will have it. Plate marked Haskell's Exhibit Number 1 for Identification 2/17/09 H. J. R. X Ex."

A. The question is what?

Q. Whether you had that in mind?

A. I had.

Q. I ask you whether or not you do not find that the increments which are marked on "Haskell's 1 for Identification" to which I just directed your attention, and which was identified by the witness as above stated, correspond with the in-

crements appearing on Table XXIII of the same Appendix to the report, in which Table XXXVII referred to on yesterday appears?

A. I do.

Q. I wish you would take the increments appearing on Table XXIII on page 53 of the report of the International Waterways Commission, for the St. Clair, Detroit, Niagara and St. Lawrence Rivers, and reduce those increments to the corresponding loss of level of lake surface, in inches?

A. For 10,000 cubic feet?

Q. For 10,000 cubic feet.

A. What is the particular one you want reduced?

Q. Commencing with the St. Clair, Harbor Beach.

A. You want them all, or the mean?

Q. All stages.

A. The first one given as a mean. As the result of the division of 10,000 by 18,900, I read from Barlow's Tables, .5291005.

Mr. Austrian: That was for St. Clair?

A. That is for the mean stage of St. Clair, according to the table in the International Waterways report.

For the division of 10,000 by 16,300, I read in Barlow's Tables .613.

Q. What is that for?

A. That is for the elevation from 579 to 580, for elevations of Lake St. Clair.

Mr. Austrian: You are asking for all those?

Mr. Wilkerson: Yes.

A. For the division of 10,000 by 17,500, I read .571.

For the division of 10,000 by 19,100, I read .524.

For the division of 10,000 by 20,900, I read .478.

You do not wish anything about the Detroit?

Mr. Wilkerson: Yes, go right down, because I have some other questions that may make it convenient for you to have those right before you for your own computations.

A. For the division of 10,000 by 20,600, I read .485.

For the division of 10,000 by 18,300, I read .546.

For the division of 10,000 by 20,900, I read .478.

For the division of 10,000 by 22,500, I read .444.

Coming to the Niagara:

For the division of 10,000 by 23,400, I read .427.

For the division of 10,000 by 19,600, I read .510.

For the division of 10,000 by 21,400, I read .467.

For the division of 10,000 by 23,200, I read .431.

For the division of 10,000 by 25,100, I read .398.

Coming to the St. Lawrence:

For the division of 10,000 by 28,100, I read .356.

For the division of 10,000 by 26,800, I read .373.

For the division of 10,000 by 27,600, I read .362.

For the division of 10,000 by 29,300, I read .341.

For the division of 10,000 by 29,800, I read .336.

Please reduce those to inches.

A. You want them all, or do you want the maximum, minimum and mean?

Q. No, I would like to have them all.

A. The first value given for the St. Clair gives 6.33 inches.

Q. Give it the nearest eighth, quarter or half.

A. I would say approximately for St. Clair mean increment $6\frac{3}{8}$; for the minimum increment $7\frac{3}{8}$.

Next I would make $6\frac{1}{8}$; the next $6\frac{1}{4}$, and the last on the St. Clair $5\frac{3}{4}$.

Mean for the Detroit about $5\frac{7}{8}$, minimum $6\frac{1}{2}$, the next $5\frac{3}{4}$, $5\frac{3}{8}$. $5\frac{1}{8}$, that is mean for Niagara. For the minimum increment of Niagara $6\frac{1}{8}$; the mean is $5\frac{1}{8}$; minimum $6\frac{1}{8}$.

The next is $5\frac{3}{8}$.

The next is actually about 5 3/16. The last one, that is the highest increment for Niagara $4\frac{3}{4}$, and the St. Lawrence the mean is $4\frac{1}{4}$; minimum is $4\frac{1}{2}$.

The next $4\frac{3}{8}$; the next $4\frac{1}{8}$; the last 4 inches.

Q. It is a fact, is it not, that the effect upon the level of the lakes for the diversion of a given quantity of water is greater at low stages of the lake than it is at high stages of the lake?

A. Yes.

Q. I call your attention to your Table Number LXV?

A. Yes.

Q. The same being table of elevations and mean elevations of lakes, 10 years prior and for ten years subsequent to the opening of the Chicago Drainage Canal?

A. Yes, sir.

Q. The figure which you have put down there for the mean elevation of the lakes, the mean elevation of Lake Michigan from the year 1890 to the year 1899, is 580.342?

A. That is from 1890 to 1899?

Q. Yes. That represents a stage how much lower than the mean stage as stated in Table Number XXIII?

A. Substantially 13 inches, a foot and one-tenth.

Q. So that if we were to take the figure from Table XXIII which applies to the conditions represented by an average of

580.342, that would take the figure 580.581, which would be 6⅞ inches, would that not, approximately?

A. That is according to the table.

Q. I am speaking according to the table?

A. Yes.

Q. Now take the St. Clair elevation, the mean is 575.013 if we were going to take a figure which would represent that condition, we would take——

A. You ask what I would take from this table?

Q. Yes.

A. From Table XXIII for the elevation of Lake St. Clair, I would split the record from 574 to 576 and call it 19,600 for the increment, which would be 6½ inches.

Q. Now take the Erie elevation of 572.012.

A. That is the same situation that we had before, and I would call that 5⅜.

Q. So far as these figures in inches are concerned, the figures for the mean as you have stated them for the period 1900 to 1909 would not be substantially different?

A. No, you would reduce—that is depending on reading from this table, one would naturally reduce the effect slightly on St. Clair and Erie, that is having gotten well up into that foot by reading from this table, a person would hardly split, but the results would be substantially the same.

Q. So that in arriving at the real effect which must be kept in mind for the purpose of the inquiry which we have here, it is necessary to take into consideration the effect of the given diversion at the low stages of the water, is it not?

A. That is contrary to the testimony of every witness in this case, they all having specifically stated that for the purpose of this investigation the increment could be represented by a straight line, which means that the increment for the purposes of this case and for the range covered by it is substantially the same at all stages.

Q. I am speaking of the effect of the lake level as the result of the diversion of a given quantity of water. I think you misunderstood my question.

Mr. Adcock: In other words your proposition is there might be some slight difference between high and low stages?

Mr. Wilkerson: What I have in mind is this: That the effect of the diversion of a given quantity of water would be greater at the low stages of the lake. That is a fact, is it not?

A. Theoretically.

Q. Yes, theoretically it is greater and practically so.

A. Let me make this correction to my previous answer, where I said every witness answered, make it: Every witness of whom the question has been asked.

Mr. Adcock: That is they did not make any distinction so far as this case is concerned?

A. That is it, for the purpose of this investigation, for the line covered in this investigation.

Mr. Wilkerson: Without regard to what these other witnesses have said, it is a fact that for the low stages, you have to increase the figures showing the effect upon the lowering of the lakes to an extent as indicated by the figures which you have given.

A. Not at all.

Q. I am speaking of the table itself.

A. Oh.

Q. I am not asking whether in your opinion the table is inaccurate, because of course you have said the engineers are wrong. I am asking you to assume the accuracy of the figures which have been prepared by the Government Engineers.

A. I did not understand that assumption to be included in your question.

To state an answer formally to your question, I would say this: That according to the table which is presented on page 53, and upon theoretical conditions which I believe to be accurate conditions the effect of a diversion at the elevations existing from 1890 to the present time would be greater than the effect of a diversion at the elevations which are presented as the means in Table XXIII of the report of the International Waterways Commission on Lake Erie.

Mr. Adcock: That is the mean for the entire period?

A. No, what they state here as the mean. That is a fair answer to your question.

Mr. Wilkerson: By mean stage as used in this table is meant the mean from the year 1860, isn't it?

A. I can't say as to that for the moment. I think that it is, but it does not make any difference whatever that mean is, it is higher than the stages that have existed since 1890 to the present time.

Q. I understood you to say it was your opinion that the effect of excavations which had been made in the Detroit and St. Clair Rivers has been to permanently lower the levels of Lakes Michigan and Huron by about a foot, .6 of a foot to a foot?

A. Six tenths to a foot I think was my estimate with possibly one foot and .2.

Mr. Adcock: You mean under the conditions as they exist now, as far as "permanently" is concerned.

Mr. Wilkerson: I mean assuming that condition remains as it is, it would be the effect of it according to his testimony.

Q. Now what are the influences which in your opinion have a tendency to reduce the actual mean level of the lakes?

Mr. Adcock: You mean to reduce them or affect the levels?

Mr. Wilkerson: To reduce, I said.

A. You mean other than the deepening of the channels?

Q. Yes.

A. The clearing of the lands on the water sheds of the tributary areas and the diversion of water at Chicago; and of course the levels of the lakes are subject to variation, on account of variations of rainfall and evaporation.

Q. Is it your opinion that the effect of the removal of the forests and cultivation of the soil is to diminish the quantity of water which flows into the lakes?

A. No, sir.

Q. And thereby reduce the level?

A. No, sir.

Q. What do you have in mind?

A. It increases the rapidity of the discharge into the lake and gives it an opportunity to get out of the lake more rapidly, so that the low water is lower.

Q. And that is the process of reasoning by which you reach the conclusion that it does have a permanent lowering effect?

A. That is the process by which I arrive at that conclusion.

Mr. Adcock: Do the extensive drainage operations have anything to do with that?

A. I had that in mind also in my answer, whether I stated it specifically or not, that with the cutting off the forests comes the cultivation of the land, all of which tends to increase the rapidity with which the water reaches the lakes.

Mr. Wilkerson: You stated, Mr. Williams, that no one had been absurd enough to suggest an increment of 16,000 for Lake St. Clair?

A. I said less than 16,000, I think.

Q. You do find in Table Number XXIII an increment of 16,300 feet?

A. I do.

Q. Stated for the stage 579.580?

A. I do, but that is not an average stage, not an average increment, however, and it is not within the range of my answer, either, as I said less than 16,000.

Q. You have produced in evidence a number of charts, plates and tables.

Mr. Adcock: You are referring to all of Williams Exhibit 34?

Mr. Wilkerson: Referring to a compilation which we have been designating as Williams Exhibit 34 in this case.

Q. About when did you begin the preparation of these tables, charts and plates?

A. As soon as Mr. Shenehon's evidence was presented, or in fact while it was being presented, that being the first opportunity we had to get any reliable information, or information which we understood would be accepted along the line of evidence bearing upon these problems.

Q. Were most of these tables, plates and charts prepared about the time he testified?

A. Oh, no.

Q. They were prepared some time afterward?

A. From that time until a few days ago.

Q. When did you prepare the first table in which you made use of the method of referring the discharge measurements to a different elevation of the lake from the method which had been employed by the Government Engineers in that respect?

A. I don't understand the intent of your question. I don't understand what you are trying to get at.

Q. (Question read.) I am referring now to the tables in Exhibit 34, and you have a series of tables there in which you have corrected, as you say, the stage to which the discharge measurements are to be referred.

Mr. Austrian: Don't you think you ought to separate that question?

Mr. Adcock: You ought to designate the tables.

The Witness: You are referring to the tables of the discharge of the St. Clair River.

Mr. Austrian: The question is involved, incorporates two questions in one.

Mr. Wilkerson: I think the witness understands what I want.

The Witness: You are referring to the St. Clair River, are you?

Mr. Wilkerson: Any river.

Mr. Austrian: Just give him one table for example. When

did you prepare the first table that is computed upon the basis other than that employed by the Government?

Q. (Question read as follows:) ("When did you prepare the first table, in which you made use of the method of referring the discharge measurements to a different elevation of the lake from the method which had been employed by the Government engineers in that respect?")

A. That question really, Mr. Wilkerson, I must say is not clearly intelligible to me. I think it is possibly my fault; that I do not understand the terms that you are using. I will be very glad to do my best to answer the question for you if you will tell me what you are trying to get at.

Let me ask if this is what you mean: Do you mean to ask when it was that I first began the investigation of the effect of the discharge based upon what I have considered normal conditions since 1890?

Q. When you prepared your first table, which is of the same kind as table number——

A. You mean something in the nature of Table XXIX?

Q. (Question re-read.)

A. If you mean by that when did I first combine the observations in consecutive groups, for the purpose of comparing them with the lake elevations existing over a period of several days, that work was done during the summer of 1909, or immediately following the conclusion of Mr. Shenehon's examination.

Q. Were the tables which have been produced in this case prepared then?

A. Some of them were.

Mr. Austrian: You mean all the tables?

Mr. Wilkerson: Which ones were prepared as early as 1909?

A. Table XXVIII was prepared at that time.

Q. Any others about that time?

A. Oh, yes, there were a large number of them.

Q. I would like to have the ones that were prepared in 1909.

A. Table 1 was prepared at that time. The table of which this print is made is a redrawing of it due to the fact that the sheet became damaged. Table II, I think is a print of the original table.

Table III, Table IV, Table V, Table XIII, XIV, XV, XVI, XVIII, XIX, XXII, XXIII, XLI, XLII, XLV, XLVI. In this answer, I must be allowed to extend over into 1910, because I

cannot exactly distinguish between what was done in 1909 and 1910.

Q. I understand you to say it takes in 1909?

A. No, and I am giving you the tables here of those that were prepared in the first investigation of the subject, after Mr. Shenehon's testimony was presented, and that covered the balance of 1909 and some work in 1910.

As we went on with the work, we found we wanted additional information and we asked for it, and got information that was not put in the record at the time that Mr. Shenehon testified.

Q. You have some idea; I want the order in which you did this work.

A. I am giving this to you. The work on this embraces, you might say, three periods, leaving out an amount of preliminary work that was done before any testimony was taken in the case, which was based upon solely what might be found in reports, and was not at all conclusive.

The testimony of the complainant closed on June 5, I believe, 1909, or rather, the testimony of Mr. Shenehon closed June 5, 1909.

Mr. Austrian: That is the same thing.

The Witness: No, they examined Mr. Coulby after that. And we immediately began work on this data and continued until along into 1910. Then there was a cessation of activities, and quite a lapse of time which I do not recall, until the matter was stirred up again, and some further investigations were carried on. And then finally last fall the matter came to a head a third time and we proceeded to make further investigations, or to complete, rather, the investigations that we had under way.

As a matter of fact, when the need for the work had apparently disappeared temporarily at least, we having numerous other things to attend to, we simply shelved it in our office and left it for future study.

Mr. Austrian: Then the numbers you are calling off are the numbers prepared in the second period?

A. No, first period.

Q. And that centered in 1909, along in 1910?

Mr. Wilkerson: Along into 1910.

The Witness: Table XLIX, the first sheet of Table XLIX, and the first sheet of Table L and the first sheet of Table LIII; I might also say in regard to Tables XVIII and XIX, that the original table—that the portion of that actually presented here which was compiled during this first period of

investigation as represented on the first sheet of those respective tables, that the second sheet has been re-drawn to extend the observations to 1912. The original sheet stopped in 1908 and we simply copied the preliminary portion of the sheet and added to it what is necessary to bring the information to 1912.

Q. Were any of these tables you prepared in 1909 and 1910 ever submitted, either to the Secretary of War or the Chief of Engineers, in connection with any matter there pending relating to the Sanitary District?

A. Not to my knowledge. It is possible that there might have been, as copies—well, I won't be sure whether a copy was in the possession of anybody who may have submitted it.

Q. You were never called upon to make a statement or any explanation to accompany those tables, to be presented to the War Department?

A. No.

Q. I direct your attention to Table XLV a, consisting of five sheets.

A. Yes.

Q. When was that table made?

A. That table as presented here was made recently, at the request of Mr. Shenehon. It was copied from a table made in pencil, which was made in 1909. We simply had the thick paper with its computations in pencil. We did not regard that as of sufficient importance to introduce ourselves, but when they were asked for we had them copied in blue prints.

Q. Have you utilized this table in deriving an increment as to which you have given evidence in this case?

A. That table is the basis, I believe, of Table XLV.

Q. I direct your attention to sheet 2 of that table and to group 5, and ask you to state the dates on which the observations which are there utilized were made?

A. Group 5?

Q. Yes?

A. The date would indicate that they were made in February. I suspect that that, too, is an error.

Mr. Shenehon: That is correct.

The Witness: Were they made in February?

Mr. Shenehon: Yes.

The Witness: I have forgotten that there were observations made in February.

Mr. Wilkerson: What is the answer?

A. I say the date would indicate they were made in February.

Q. February 14, 15, 16 and 17, 1899?

A. Yes.

Q. If you have any doubt on this subject, I ask you to refer to the tables from which observations 93 to 102, inclusive, were taken.

A. I haven't any doubt. The thing that I had forgotten was that observations were made in February. Yes, that is all right.

Q. To what tables are you now referring?

A. I will have to get my copy of it so as to see what that exhibit is.

Mr. Adcock: I think that is Williams' Exhibit 24.

A. Williams' Exhibit 24.

Mr. Wilkerson: These observations on which the conclusions are stated, as the result of which this table was made, were picked out by you with particular care, were they not, Mr. Williams, so as to get observations which would represent the normal conditions?

A. They were picked out with reference to the mean elevation of Lake Erie for the days during the observations, as indicated in the record of the Buffalo gage.

Q. And for open season conditions?

A. For the conditions which existed when the observations were made. I don't know whether the river was open, or closed with ice, but I assume it must have been open.

Q. You do not understand that in reaching a result with reference to this increment, it would be proper to include observations taken when the river was closed with ice, do you?

A. Not for direct comparison with those for the open season, no.

Q. Now, I call your attention to the note at the bottom of Table Number 1: "Summary of discharges International Bridge Section Niagara River," and to the following.

Mr. Adcock: You are referring to Exhibit 24?

Mr. Wilkerson: The same being Exhibit Number 24 as follows: "Numbers 116, 117 and 118, span 1 blocked with ice. 114, span 9 blocked with ice. 91, 92, 100, 101, 102, spans 1 and 9 blocked with ice. 93 to 99 inclusive, spans 1 and 9, and east half of span 2 blocked." I will ask you whether or not those notes do not indicate to you that there was ice in the river at that time?

A. They indicate that to my mind at the present moment, yes, sir.

Q. In your opinion as an engineer, do you regard it as proper to incorporate those observations taken in February, 1909, with the open season observations with which they have been incorporated?

A. Well, that is an error which escaped my attention until this moment. I may say—

Q. Do you know now whether as a matter of fact you have used these observations in which the river was blocked with ice in any other comparisons which you have made?

A. I presume that they have been used in all of them, as all of these comparisons with gages have been based upon this same table.

Q. Were any of those used in Table Number 3?

A. In Table Number 3?

Q. In which you have made a criticism of the Niagara work, comparing its accuracy with the work on the St. Clair and the St. Lawrence Rivers, having derived the average variation from the mean?

A. So far as I see, this table of comparison of observation 83 with observation 116 would be an unfair comparison, for the reason that in 116 span Number 1 was blocked with ice, whereas in 83 it was not. Let me go through these and make sure that there are not any more.

Q. How about 18 and 121?

A. Apparently there is nothing to indicate that there was anything wrong with 121. Am I right, Mr. Shenehon? I do not see it here in the notes.

Mr. Shenehon: The date indicates it.

Mr. Wilkerson: March 24th?

A. You specifically state what is the matter with these various ones, and omit 121. I simply want this for my own protection, that is all, that so far as the notes on Exhibit 24 are concerned, there is nothing there stating that there were any abnormal conditions in the case of measurement 121. It is, however, a fact that that observation was taken on the same day as observation 120, which states that the discharge for span 2 was interpolated, and the measurement 119 which states that the discharge for spans 1 and 2 was interpolated.

Q. Referring to the comparison based upon the use of observations Number 83 and 116, I direct your attention to the fact that the per cent. of variation from the mean which you get by reason of the use of that observation 116, is 5.27 per cent.?

A. Yes.

Q. State whether or not that would not indicate to you

that the improper use of these ice observations has been an important factor in getting the figure of 2.89 as the summary of the—

A. It is entirely correct that that comparison should not have been included in this table; and it was included through a neglect on my part to take cognizance of this note at the foot of this discharge table, and to that extent—

Q. Or the date?

A. Or the date. That was a clean oversight, and the average variation as shown in this table should be reduced by the effect of eliminating that 5.27, shown by the comparison of observations 83 and 116.

There may be another one here, Mr. Wilkerson. Let me be sure.

Q. There are observations 112 and 92?

A. 112 and 92 were both under ice conditions. Whether the conditions were the same or not—there is nothing in the note apparently to indicate directly what the condition in 112 was, and we may or may not assume that it was similar to the conditions in 116 or 102. If similar to 102, it is similar to 92.

Q. Of course, the open season conditions, it would not be proper to use either one of those observations, would it?

A. Yes, for this purpose, we are not considering whether it was open season or closed. What we are endeavoring to do is compare observations under similar conditions. These observations 112 and 92 would compare with each other. They are not compared with any others—

Q. Did you use the same method on the St. Clair, incorporating winter observations?

A. On the St. Clair we took into consideration all the observations that had been introduced in the testimony and we compared those that had been taken under what the evidence indicated, as we understood it to be, similar conditions.

I am perfectly frank to say right here, gentlemen, that I based these comparisons on similar stages, and overlooked the fact that these were winter observations. I am perfectly frank to say that, and I am very glad my attention has been called to it; and I will have this table corrected to eliminate observations in which comparisons are made under conditions which are not similar. I will be glad to sit down with Mr. Shenehon and ask him to assist me in selecting the ones that do represent similar conditions.

Q. So that any place in which these tables have been used as the basis of conclusions reached in this case, the conclusions which have been reached and the use which has been

made of them, so far as their effect upon other witnesses is concerned, will be subject to the correction of these tables by the elimination of these observations.

A. They will be subject to that correction.

Mr. Adcock: You say the elimination of the observations?

A. Oh, no, they will be subject to a correction to meet the action conditions. If during a winter measurement when the conditions were the same on two days, we have these variations, then they are entitled to be in here. But it is not right to compare a case when we had spans blocked with ice with a case when we did not; nor is it right to compare cases when only one span was blocked with ice with cases where more than one were blocked with ice.

Q. As a matter of fact, aren't the conditions such in the winter season that it is regarded as improper to use the winter observations for any purpose, in comparison or otherwise; the ice conditions changed so from time to time. There may be ice around the Niagara Falls?

A. I will answer that question by asking, then, why the Government wasted the money to take them if they are improper to use for any purpose?

Q. I think I referred to Table Number 3, as to the use which was made of that as to the correction which would have to be made, and I applied it also to Table XLV a. If I did not, I ask you whether that is true as to Table XLV a, also?

A. It is.

Adjourned to Monday, July 21, at 10:30 a. m.

Monday, July 21, 10:30 a. m.

GARDNER S. WILLIAMS resumed the stand for further cross-examination by Mr. Wilkerson, and testified as follows:

Q. Referring to the increment of the Niagara River, Mr. Williams, is it a fact that in deriving that increment you utilized the principle of the ratio of increment to fluctuations of lake surfaces over periods of years?

A. You mean the increment as testified to finally, the value of 34,000?

Q. I mean in your computations of the increment for this river, did you make use of that principle in any of the tables which have been presented by you?

A. It was not used in connection with any tables from

XLV to XLVII a, inclusive. It was used in getting at the value which I finally adopted as being the most likely, or as being a probable value.

Q. I will ask you to explain how you made use of the principle of the ratio of increment to fluctuations?

Mr. Adcock: What fluctuations do you refer to, oscillations?

Mr. Wilkerson: To the fundamental proposition on which that principle is based.

Mr. Adcock: You mean the monthly, yearly or daily?

Mr. Wilkerson: Well, a given period.

Q. If you will, explain that to us first in a general way, and then take it up by reference specifically to your tables; it might be clearer?

A. I will have it for you in just a moment. The general principle involved is that if any reservoir, or if rather, two reservoirs, have openings of different sizes and water flows into both of them in amounts varying, that the one which has the opening with the larger increment will change its level less than the other for the same quantities of inflowing water, or the same rate of inflow.

Q. And it is your opinion that this proposition is applicable to the Great Lakes, treating them as water reservoirs, as you have stated?

A. It is.

Q. The proposition is still applicable where the quantities of water are different, as in the case of the three lakes we have under consideration here, is it not?

A. Yes, it is still applicable.

Q. Except that you have to make allowance for the difference in quantity. The proposition remains the same. Do I state that correctly?

A. Yes, that you must take into account the difference in quantity.

Q. The difference in quantity of water, but that, making allowance for that, the general proposition applies?

A. (No response.)

Q. Now, coming back to the use which you made of it in this case, I will ask you to explain a little more in detail by reference to the tables which you have submitted, in just as simple a way as you can, just what use you have made of them, having in mind that this case is to be argued by lawyers and heard by a judge?

A. Take, for example, Table XXI, we find that if the elevations of Lake Huron, for instance, be plotted as ordinates

to the elevations of St. Clair abscissas, that they fall in a line, or they approximate to some sort of a line; and that if the mean line be constructed a ratio will be derived for the fluctuation of one lake in terms of the other, as testified to by the complainant's witness Shenehon, page 592 of the continuously paged record, that when Lake Huron goes up a foot Lake Erie goes up .7 of a foot. This is more specifically explained previous to that, but that happens to be the reference I have a knowledge of just now.

Q. In your own opinion, that portion of his testimony is correct, is it?

A. Based upon what he was stating, that is, upon the average results extending from 1860 to 1908, which I understand is what was included in the basis of his answer, I think agrees substantially with the results which we have obtained.

Mr. Austrian: On that point.

A. On that point. Then if for the same quantity of water flowing in to both Lakes Huron and Lake Erie, Lake Erie is raised .7 of a foot as Lake Huron is raised a foot, it means that the increment of Lake Erie must be to the increment of Lake Huron inversely as the changes, or as 100 to 70.

If in addition to that, there is a further inflow into Lake Erie not accounted for or not received through the outlet of Lake Huron, then the indication would be that the increment of Lake Erie must be still larger, as it has to take care, not only of the water coming from Lake Huron, but such as comes from its natural drainage.

Mr. Wilkerson: Now, you spoke of plotting these elevations. If when you plot the elevations of these two lakes, in the way in which you have stated, they tend to arrange themselves in a line, is that an indication to your mind that the relation which is represented by that line is the correct relation for the observations used?

A. That line is a correct representation of the relations between the observations used, considered as a whole.

It must be borne in mind that by taking short periods, different results are obtained than in the case of long periods; that individual years may show apparently erratic indications, but for a general relation covering the period considered, that line indicates the ratio of one change to the other, based on the whole period. It might be a straight line, of course, or it might be a curve. For the purpose of this case the straight line has been utilized.

It is entirely possible that a final analysis might show that at high stages the relation between the fluctuation was differ-

ent from what it is at low stages. But that was a phase of the matter that has not been considered up to the present time; and I question very much if the information we have is sufficient to arrive at any satisfactory conclusions along that line, because the observations do not cover a sufficiently long period; and are influenced by changes in the conditions of the discharging channels.

Q. That last statement has to do with the curvature of the line?

A. Yes.

Q. And not to the establishment of the law?

A. No, that deals with the question of curvature of the line.

Q. I understand it to be the effect of your testimony, looking over these tables which have been submitted, that you by a similar process of reasoning worked back from the increment of the St. Lawrence to that of the Niagara, is it?

A. It is.

Q. So that we may have it here, state just briefly, and as simply as you can, your process of reasoning by which you work back from the St. Lawrence to the Niagara?

A. The process is simple; by a plotting of the elevations of Lake Ontario and Lake Erie, and an analysis of the results presented in Table XLIV, we get the relation of the change of Ontario to the change of Erie.

Q. It is there stated at 136 per cent.?

A. Yes.

Q. And you have adopted that ratio, and then combined with it your computations relating to rainfall and evaporation?

A. The tables of rainfall and evaporation, I believe, are not combined with this increment. The treatment of rainfall and evaporation does not involve the fluctuation of the lake surfaces except as actually measured to determine the storage that has accumulated or been lost from one lake to another. It has nothing to do with this relation.

Q. Does not enter into this 136 per cent. at all?

A. Does not enter into that 136 per cent.; at least that is my present recollection.

Q. In the case of this table which you have before you, Number XLIV, do the rainfall evaporation and run-off interfere materially with the operation of that law which is there deduced?

A. The rainfall and evaporation has not been taken into consideration in this table, it being based solely upon the relations of the lake elevations, and this ratio is that which is

shown by the actual changes of elevations, without inquiring as to their cause.

Q. In making this transfer, do you regard it as proper to ignore the elements of run-off, rainfall and evaporation?

A. It is reasonable to make a correction for the effect of local supply, which I assume to be the point that you are getting at.

Q. Yes. But you regard the method as substantially correct, notwithstanding any differences that might result from the rainfall, evaporation and run-off?

A. I would say that so far as this analysis is concerned of connecting the St. Lawrence with the St. Clair that the corrections on the outflow of Ontario due to the rainfall there are of the opposite sign to those that would be applied at Erie. And when those corrections have been made, it is my opinion that you will get to the same result at the St. Clair, substantially. In other words, that the St. Lawrence discharge will check St. Clair as it is in this computation.

Q. You can pass from the St. Lawrence to the St. Clair and also from the St. Clair to the St. Lawrence?

A. Certainly.

Q. According to the method which is stated here?

A. Yes.

Q. It applies eitherway?

A. It applies either way. Of course, you must realize that it is only as approximation, inasmuch as you cannot accurately determine the effect of that local supply. That is the thing that coming in there makes this an approximate comparison.

Q. What, in your opinion, are the limits of the precision, in the method of going from one lake to the other in the way in which you have just explained?

A. If there were no variations of inflow and outflow due to the local supply and local evaporation, the method would be strictly accurate, assuming that the data upon which it is based are accurate; that is, that the ratios are the correct ratios. It will be affected to the extent to which the variations of local supply and local evaporation cause fluctuations of the lake surface in the second lake in the comparison.

Now, as to how much that is, I am not prepared at this moment to say, for the reason that at times the inflow from the local drainage may accentuate the fluctuations, and at other times it tends to suppress them, and considering a long period of years these effects will to a greater or less extent

neutralize, and it would involve quite an extended study for me to be able to express an opinion in a percentage.

Q. Just what is the increment, according to your method, of the Niagara as derived from the St. Clair?

A. I don't recall that I specifically derived the increment of Niagara from the St. Clair. Considering the results of computations both ways from the St. Lawrence and the St. Clair, I arrived at 34,000 as being as low a value as seemed to me reasonable for the Niagara.

Q. The increment of the Niagara as derived from the St. Clair is more intimate, so to speak, than the increment of the St. Lawrence as derived from the St. Clair?

A. I would say not necessarily, for the reason that going through Lake Erie, and Lakes Erie and Ontario, the local supply effects of one balance the similar effects of the other, and I think that the relation between the St. Lawrence and St. Clair increment is more nearly correct than a relation that would be derived from either for the Niagara.

Q. It may be that I do not catch your idea.

A. Perhaps I do not catch the trend of your question, Mr. Wilkerson. I am trying to follow you.

Q. We are working from the increment of one river to that of another. The Niagara River, of course, is much nearer to the St. Clair than the St. Lawrence; and the question was whether the Niagara River stands in your opinion in a more intimate relation, as far as the determination of this increment is concerned, to the St. Clair than did the St. Lawrence, on account of the greater distance?

A. I think, considering all the factors of the problem, that the derivation of the increment of the St. Lawrence from the St. Clair, or the increment of the St. Clair from the St. Lawrence is more likely to be correct than the derivation of the Niagara increment from either one, for the reason, as I stated before, that the local supply effects and local evaporation act in one sense in the case of Erie, and in the opposite sense in the case of Ontario and tend to cancel each other's influences.

Q. Just about how much more nearly accurate do you think you could go from the St. Clair to the St. Lawrence than you could go from the St. Clair to the Niagara?

A. Depending altogether upon the magnitude of the local influences in Lake Erie and Lake Ontario.

Q. Have you in your own mind any opinion that could be expressed in the language of percentages?

A. I have not at this moment.

Q. And what you have said would apply in going back from the St. Lawrence to the St. Clair?

A. Yes.

Q. You think you could go more accurately from the St. Lawrence to the St. Clair than you could from the St. Lawrence to the Niagara?

A. I think your results would be more accurate when you had gotten there, in the former case.

Q. Of course, the method which you have used could be used starting at the Niagara and working either way, provided you had an increment?

A. Yes, if you had an accurate increment.

Q. Which is derived from observations at Niagara?

A. If you had an accurate increment for the Niagara River you could go both ways from that and expect to get reasonable results. If you didn't have an accurate increment, you could work both ways and get unreasonable results.

Q. In deriving the increment of the St. Lawrence River, did you take into account the changes which were produced by the construction of the Gut Dam?

A. I don't see from the dates on the St. Lawrence gagings, as I understand it, that the Gut Dam had anything to do with the situation at that time.

I will correct this answer of mine by saying that I understood that the effect of the Gut Dam was not effective until 1904, as the year 1903 has been included in the table, showing the relative elevations of Lakes Ontario and Erie. If the Gut Dam were influential in 1903, then a very small correction, the sign of which I am unable to state at this moment, would have to be made in that ratio.

Mr. Austrian: For that year?

A. No, the ratio for this whole table; it would be one year out of forty-three.

Mr. Wilkerson: The effect of the Gut Dam was to lessen the flow of the St. Lawrence River for a given stage, about 5½ per cent., was it not?

A. It was to raise Lake Ontario about 5 inches. I don't remember the percentage of that. I think, on recollection, that the 5½ per cent. is approximately correct, as I believe I connected those two figures, that it was substantially the same number of inches as it was per cent.

Q. And that change of 5½ per cent. would have to be made in the increment, in order to give expression to the effect of this dam, would it not?

A. The effect of that dam should be corrected in Table

XLIV. Whatever effect it had in 1903 should be used to reduce the elevation of Ontario for that year.

Q. The thing to which I had reference in my question was the effect upon the increment, and I understand that effect is one which would show itself immediately, or substantially so.

Mr. Austrian: Immediately upon the completion of the dam?

Mr. Wilkerson: Yes.

A. The increment as derived in this testimony and applied is based upon the increment of the St. Clair River, as is shown by the information which was presented by the complainant in this case.

I am not aware that the complainant anywhere in its testimony introduced the subject of the effect of the Gut Dam upon the increment of the St. Clair River—or the St. Lawrence River, or corrected his (Mr. Shenehon's) increments to compensate for it.

With that obstruction it is possible, though not certain, that the increment of the St. Lawrence River now is less than it was prior to the construction of the dam. But there has been since then constructed another compensatory work of a different character, a channel in the vicinity of the Gut Dam, which is shown upon Williams' Exhibit 18 and is there designated at the North Channel. This is a channel which has been constructed through a portion of Drummond Island and is from 17 to 19 feet deep and about 300 feet wide. The Gut Dam closed a channel about 400 feet wide and less than 18 feet deep, and was located within a mile of the North channel. It would seem, therefore, that the construction of the North Channel must have to a considerable extent compensated for the effect of the Gut Dam.

Q. But dealing with the effect of the construction of the Gut Dam is an independent element, in order to determine the effect of the loss of outflow upon the increment, you would reduce the increment by approximately the same per cent. as the outflow was reduced. If you were dealing with that just as an independent factor and wanted to determine what its effect was upon the increment, you would reduce the increment by a per cent. which would be in accordance with the loss of outflow?

A. That would be only true during the period when the lake was re-adjusting itself. When the lake arrived at its new elevation, it is very probable that the increment would be found to have been increased by reason of the probably

broader channels that would be available for the discharge of water on account of higher elevation.

During the period when the lake was rising, the increment would be smaller than it was in the first case, and would gradually approach its final value, which would be either smaller or greater, but probably would be greater.

Q. Have you personal knowledge as to the physical conditions under which the dam was constructed? Do you know the facts about the steepness of the banks and the channels?

A. I saw the dam the other day. It is rather an insignificant structure, cutting off a channel that extends obliquely to the general trend of the current. This new channel opens directly into the main opening of the river through the Galops Rapids, and from that inspection, it certainly appears to me that there can have been very little effect, very little ultimate effect, very little net ultimate effect of the two improvements.

Q. Is there anything further, Mr. Williams, that you care to state about the effect of the construction of the Gut Dam?

A. No response.

Q. But for a given stage, if you lessened the outflow of the river a certain per cent., you would reduce the increment by the same per cent., as a general proposition, and for small variations?

A. Yes.

Q. That is the method which you have accepted as a correct method in this case, is it not?

A. Yes, understanding you to mean that for two given stages, if the outflow is reduced for both of them by a percentage, the increment would be reduced by a similar percentage. That is what you really meant to say, I think.

Q. That is a correct principle, as I understand your testimony, that there is a relation between the outflow and the increment, and where you have a small outflow you have a small increment; and so starting in with the St. Clair, you have a given increment without regard to what it is. When you get to the Niagara you have a little larger one; when you get to the St. Lawrence, you have a still larger one, there being a relation between the amount of the outflow and the increment?

A. There is no such relation. The increment is dependent upon the cross section and slope of the outlet. For example, you might have such an outlet to Niagara that you could have an increment ten times as great as you would have through the St. Clair or through the St. Lawrence.

Q. Or even smaller?

A. Or you could have it smaller.

Q. Now, referring to the three rivers, the St. Clair, the Niagara and the St. Lawrence, I desire to get a summary of your opinion as to the elements of precision with reference to each one of those rivers, or to put it another way, the relative precision of the three rivers; I am referring to those measurements of volume.

A. Measurements of volume?

Q. Measurements of volume that you have under consideration in this case. Let us take first the stability of the lake at the outflow weir, and compare those three rivers.

A. Now, let me get your question clearly in mind. You wish me to express my opinion as to the relative dependence that is to be put upon the measurement of quantity independent of increment of the St. Lawrence, Niagara and St. Clair Rivers. Is that correct?

Q. Well, let us make it the law of discharge.

A. I do not think that the law of discharge has been established. Certain specific measurements of discharge have been made, and I have some opinions as to their relative reliability. But as to the establishment of the law of discharge, I am very clearly of the opinion that it has not been established for any of the rivers. And that is what I had in mind when I said in answer to a question on Friday that I doubted if anyone had successfully measured one of these large rivers; it being the purpose of the measurement to establish the law of discharge. And it is my belief that that law of discharge is not established.

Q. You have spoken in your testimony of certain difficulties which have been encountered in attempting to arrive at this law of discharge, and you have throughout your testimony, you have here and there stated facts and expressed opinions, which have related to those difficulties, related to the degree of credibility to be given to the conclusions which have been reached by those who have thought they could derive the law of discharge with reference to the different rivers. What I would like to have you do is to summarize, if you can, your opinion, having in mind the difficulties which have been encountered, having in mind the effect which you think those difficulties have produced.

I would like to have you summarize your opinion as to the relative degree of credibility which is to be given to these conclusions which have been reached as to the three rivers. And in connection with that I was about to direct your attention to certain particular points as to which I desire you to make the comparisons. Now, do I make myself clear as to

the general line of opinion which I wish to have you express?

A. I think I know what you wish me to express, and I must confess that I am afraid I am unprepared to express an opinion on that subject further than to say that I do not believe the law of discharge of any one of these rivers has been established. The measurement of quantity, I am ready to express opinions on, but the law of discharge means, or involves the connection of the discharges of the river with the other factors which enter into it. The discharge is an effect. The causes of that discharge are to be looked for elsewhere.

Now, the law of discharge must take into cognizance those causes, and up to the present time I feel very sure that the correct relation between cause and effect in the discharge of the rivers flowing from the Great Lakes has not been established.

Q. Well, let us take certain particular points, then: I direct your attention to certain particular points which would appear to be factors to be taken into consideration in arriving at a professional opinion as to the degree of credibility to be given to these conclusions of the Government's Engineers as to the law of discharge of these respective rivers. Now. I would like to have you take the three rivers and compare them from your point of view upon the points to which I have called your attention. Let us take first the stability of the lake at the outflow weir, and take the three rivers.

A. Considering the outflow weir as the point where the gaging measurements were made, I think the St. Lawrence has the advantage.

Q. We will specify the particular points: Lake Huron at the head of the St. Clair River; Lake Erie at Buffalo, and the St. Lawrence near the Galops Rapids.

A. The St. Lawrence has the decided advantage.

Q. I want all three of them compared.

A. The St. Clair ranks next and the Niagara is the most difficult, most unfavorable.

Q. As to the stability of the lake?

A. Well, as to the conditions that are encountered—

Q. I am speaking now of the stability of the water surface at those three points.

A. I think that is correct.

Q. Now, let us take the distance of the gaging section from the lake.

A. The gaging station on the Niagara was the nearest to the lake; the St. Clair would be next and the St. Lawrence the furthest away.

Q. And in your view, what effect does that have upon the credibility to be given to the deductions as to each of the three rivers, that factor alone, and other things being equal?

A. That would be a factor in favor of the Niagara.

Q. And which would come next on that?

A. St. Clair.

Q. And the St. Lawrence last?

A. Yes.

Q. Now, let us take the range of lake stages covered by the observations.

A. The range of lake stages are 3.92 feet for the Niagara; 2.43 feet for the St. Lawrence, and 1.74 feet for the St. Clair.

Q. Now, other things being equal, and dealing with that as a separate factor, would the fact that as to one river the observations had been so conducted that a larger range of lake stage was covered have a tendency to give added weight to the deductions which were based upon those observations?

A. Considering all other things being equal, including the maximum range of variation of the lake surfaces, that is, that the rise and fall of all the lakes is the same, we would consider the observations the most reliable which covered the widest range.

Q. I am speaking of that as an independent—

A. I will not be sure we got that in, because it is not a fact at all. The ranges covered—the proportion of the total variation of lake surfaces covered were greater on the St. Clair than on either of the other rivers, if I remember correctly.

Q. How do you make that?

A. Would it be agreeable to you to pass that question and go to the following one, and let me answer that a little later, because I find the computation is not here. The result is here, but on what I base it, at the present moment I am unable to recall.

Q. The ratio of fluctuations between Lake Huron and Lake Erie, I understood you to say a little while ago, was 70 per cent.?

A. That is the ratio of the average annual fluctuation. The maximum fluctuations, however, of Lake Erie at Buffalo are between two and three times as great as those of Huron, according to the best information that I have.

Q. You mean monthly means?

A. No, I mean daily.

Q. Daily means? And you mean including the effect of storms?

A. Yes, they affect the gage to which reference is made. Therefore, I would include them.

Q. Well, is it not your opinion that so far as the questions which we have under consideration here are concerned, it is the monthly mean level which is the correct criterion?

A. For the purpose of this comparison, I think I would make it with the monthly mean.

Q. Well, then, I don't exactly understand your last statement in its relation to what you have said before, Mr. Williams, about these variations. We are discussing these different elements of precision?

A. Yes.

Q. And I have taken them up in order, and one of them is the range of lake stages which were covered by the observations.

A. I would like to make a statement here, that I will answer a general question, if agreeable to you now, just because I am not prepared to answer this specific question.

I arrived at these percentages by reference to some value of lake fluctuation. What it is, I have not in mind now; and if I am in error, of course, I will be glad to acknowledge it. I want to find what I thought I had. The question, I would answer frankly—I will answer them all frankly as far as that goes—what I mean is, I will answer this general question: Of a series of gagings, that gaging which covers the largest proportion of the range of stage to which the discharge equation is to be applied would be considered the more probably accurate or reliable gaging.

Q. And you take the monthly mean as the criterion?

A. You should take whatever you are going to apply the gaging to as your criterion. For your general readings, you are applying to monthly means. That is as fine, I think, as anyone has attempted to go.

Q. And so far as the lowering of the lake and the diversion is concerned, what would you take, monthly mean?

A. You mean the effect of the diversion?

Q. Yes.

A. Well, the smallest unit in which the opinion is taken has been monthly mean. It has been applied to ten-year means, and monthly means, and since the increment is assumed to be derived from a straight line curve—or as long as it is assumed that the increment is constant for all elevations of the lake, it makes no difference whether you take it by the year or the month.

Q. Isn't it a fact, so far as the Niagara observations are

concerned, which have been under consideration in this case, that if you take the monthly means you have observations which are lower than the lowest monthly observations, and observations which are higher than the highest, so that the range of observations covers the whole range of lake stage?

A. That is true as to Niagara. It is also true as to the St. Clair, confining the period of investigation to that since 1890, before which time it is our belief that the gagings do not in anywise apply.

Q. Having in mind that one factor, you would expect results from the Niagara observations which would have a higher degree of credibility than on either one of the other rivers, would you not, just from that element alone?

A. Just wait a moment there, I was just thinking whether—

Q. But more particularly with regard to the increment?

A. Assuming all other conditions equal, the longer range in elevation covered by the observations would lead to a more accurate determination of the increment.

Q. For the obvious reason, if you plot the observations, the longer the line you have, the more accurate the trend.

A. Exactly. The increment is that factor in the equation which determines the inclination of the line, and that can be more accurately determined the longer the line is.

Q. Let us take as a factor in determining the credibility of these different pieces of work the number of observations and what you find as to them?

A. The St. Clair ranks first, Niagara second and the St. Lawrence third.

Q. Let us take now, the fifth to be taken into consideration in reaching a conclusion as to the credibility of these different pieces of work by the Government engineers, the duplication of sections and the opportunity for a corroborative check, what do you find as to the three rivers?

A. I would consider, as far as duplication went, the Niagara has the advantage. The St. Clair, of course, ranks next.

Mr. Adcock: When you say duplication, what do you mean by that?

A. That they had two sections—well, now, just wait a minute on that answer; I think that is pretty nearly an open question between the St. Clair and the Niagara. On the Niagara the two sections were quite close together, whereas on the St. Clair they were further apart. Considering the relative number of observations, I think I will give the Niagara a slight advantage on that.

Q. Referring again to the question as to the number of

observations, I will ask you to refer to the charts which were introduced in evidence by the Government and state what you find there indicated as to observations in the years 1907 and 1908?

A. Chart Complainant's Exhibit 3 states that the number of discharge measurements from 1898 to 1900 was 101; from 1907 to 1908 was 118, making a total of 219.

Mr. Adcock: That is on the International Bridge Section?

A. Bridge Section Niagara River.

Mr. Wilkerson: Let us take the sixth fact and consider it. Let us take the different conditions as to velocity and so forth in the various sections of the same rivers which were gaged. Take first the St. Clair now.

A. The velocities at the Dry Dock Section of the St. Clair were lower on the average than they were at Niagara, and I think lower than at the St. Lawrence.

Q. I want to first compare the conditions at the different cross sections of the same river. Take the cross sections of the St. Clair which were measured, what were the sections?

A. The section at the Dry Dock was below Port Huron, below the mouth of Black River, about five miles from the foot of the lake; and the Gorge Section, which is within about a mile of the foot of the lake.

Q. As to the velocity, the Gorge Section was about twice the velocity of the Dry Dock Section?

A. I do not recall those things.

Q. I want to get the substance, of course.

A. I should say that statement was substantially correct, without looking at the actual figure.

Q. Then take the sections in the several channels at the Delta, they have a smaller velocity than the Dry Dock Section?

A. Generally.

Q. Do you know how much smaller velocity the sections in those channels have than the Dry Dock Section, roundly speaking?

A. I would prefer not to answer those questions without an opportunity to make the necessary computations because I see that the—

Q. It is a fact that at the Gorge Section the velocity is about twice as much as the Dry Dock?

A. I am not prepared to say so at the present moment. I was under the impression it was materially greater.

Q. And that the Dry Dock was materially greater than the Delta?

A. No, I was not prepared to say that, but I would rather expect that.

Q. Notwithstanding the difference in those conditions of velocity, and other conditions which have been referred to already by you in your testimony how do those three sections on the St. Clair River check with each other?

A. The Gorge and the Dry Dock check very well. I have made no comparisons of the others.

Q. What do you mean by observations taken at two different sections checking?

A. Well, when referred to the same lake stages, lake elevations, they should give similar discharges.

Q. I will ask you to refer to the reports relating to these observations and ask you to give us the facts with reference to the velocities at the Delta Section.

A. In answering that question, I wish to say that I have as yet made no study of these discharges here, except as indicating the relative magnitude of discharges in the different Delta Sections. And to answer that question, I would think would take some little time.

Q. I will ask you, Mr. Williams, for the definite facts as to this, to look it up when we take an adjournment to-day, so that it can be put in the record to-morrow morning.

A. What is it you want?

Q. The facts with reference to the velocities in the channels of the Delta Section as compared with the velocities in the Dry Dock Section?

A. I do not find in the report as yet that those statements are given anywhere. It will involve—

Q. I pass that, and now I say, assuming that there is a material difference in the velocities between the Delta Section and the Dry Dock Section, and that the Gorge Section has a velocity about twice that of the Dry Dock Section; assuming that those sections check substantially with each other, what weight in your opinion is that fact entitled to in determining the degree of credibility which is to be given to those measurements?

Mr. Adcock: When you say "check," you mean comparing the observation with reference to similar observations?

Mr. Wilkerson: By "check,"I will accept the definition which he gave of "check."

A. The coincidence in magnitude of discharge measured at different points under different conditions of section would indicate the similarity in degree of accuracy of the work involved. It would indicate that aside from such sources of

inaccuracy as were present in all gagings—in all the measurements considered, that the observations were entitled to a degree of credibility dependent upon the coincidence of the measurements.

Q. So that the more accurately they checked, the higher the degree of credibility to be accorded to the work, even though the velocities at these different sections were different, as assumed in the question that has been put to you?

A. That is correct, bearing in mind always that those coincidences can have no effect upon errors which are continuing through all the observations, if there be any such.

Q. Wouldn't the fact that these three sections checked substantially in the way assumed in the question eliminate the item of any difference in velocity as one of the— .

A. You mean difference in velocity at the sections?

Q. Yes; as one of the sources of inaccuracy, in connection with the work?

A. Yes. I do not recognize the differences in velocity as being a source of inaccuracy, however, up to date.

Q. Now, then, I wish you would explain to us a little more in detail just what you mean by one of these sections checking with another, and try to put it in just as concise form as you can, what that checking of the two sections means to an engineer as to the kind of work which has been done in the measuring of the different cross sections?

A. If when applied to some reference condition, due consideration being made for the time element involved, if the measurements at consecutive sections on a stream agree, it would give to any engineer great confidence in the accuracy of those measurements, subject only to such conditions of error as errors of rating and errors of general method, which would be applicable alike to all points in observation?

Q. What were the sections on the St. Lawrence which have been measured?

A. The only one that has been considered in my testimony is the section at Point Three Points, which is that covered by—being Table Number I, summary of discharges, Three Point Section, St. Lawrence River, F. C. Shenehon, Assistant Engineer, May, 1906, and including 96 observations.

Q. There was a check, was there not, at Little Church Bay?

A. As to that I have no information, as no records of gagings at that section have come into my hands, as being exhibits in this case.

Q. Do you know as a matter of fact whether on the St.

Lawrence River, the measurements were checked by a check section at Little Church Bay?

A. I do not.

Q. That that you last referred to was Williams' Exhibit 25, was it?

A. Williams' Exhibit 25.

Mr. Wilkerson: Do you remember now whether or not the Government's principal witness in presenting these tables upon which the Government relies stated that the observations in the St. Lawrence had been checked by a section in the way in which I have indicated?

A. I do not recall.

Q. But so far as you are concerned, you have made no analyses of the St. Lawrence observations?

A. Except as indicated in the table.

Q. Except as indicated in the table, and no analysis for the purpose of determining how accurately the observations there relied upon check with the section which was measured at Little Church Bay?

A. No.

Q. Referring to the Little Church Bay Section check, do you find now the portion of the record in which that matter is described?

A. Little Church Bay is not mentioned. A section at Nevins Bay, Nevins Point, is mentioned, and the statement—

Q. It appears that the correct name of that section is Nevins Point Section, and not Little Church Bay Section?

A. That is the name that was used by the complainant's witness. The statement is made: "The winter measurement checked the summer measurement within less than one per cent." And in answer to further questions: "They corroborated the sumer measurements, so far as volume is concerned. The range was not sufficient to determine anything regarding the increment."

Q. Now I direct your attention to the fact that it is there stated that there was slow velocity of one foot per second, and that the measurements check within less than 1 per cent. What does that indicate to you as an engineer as to the accuracy of that work?

A. That work was of the same high degree of accuracy in its performance, as the standard established by the work of the United States Lake Survey would lead one to expect.

Q. What was the mean velocity at the Three Point Section? And I refer you in that connection to the report of the Chief of Engineers for the year 1902, page 2803?

A. According to the testimony of the complainant's witness Shenehon, page 498 of the continuously paged record, the current had a mean speed of about one foot per second on this section, referring to Nevins Point.

Q. I am referring to the Three Point Section, and I direct your attention to page 2803 of the report of the Chief of Engineers for the year 1902.

A. According to the testimony of complainant's witness Shenehon, on page 579 of the continuously paged record, in answer to the question, "What was the cross sectional area of the St. Lawrence River at the point where discharge measurements were taken?

A. 51,000 square feet, roundly."

Now, the discharge of the St. Lawrence was approximately 225,000 cubic feet per second, which would give a mean velocity of about 4.4 feet.

Q. Having in mind the fact that the measurement of one of these sections corroborates in the way indicated the measurement of the other, and having in mind the wide divergence of the velocity of the river at the two sections which were measured, what does that indicate to you as an engineer as to the degree of credibility which is to be given to the measurements made by the engineers based upon those observations?

A. Subject always to those sources of error, which would be inherent in both measurements, it indicates exceptionally good work.

Q. Of which the difference of velocity does not appear to be one of the factors which would cause doubt or uncertainty as to the result of the work?

A. Within those ranges, no.

Q. What were the two sections of the Niagara River which were measured?

A. The International Bridge Section and the Open Section so called.

Q. And what were the different conditions as to velocity in the two sections which were there measured?

A. The cross section at the International Bridge is stated by complainant's witness Shenehon, on page 580, to have been 39,000 square feet, and that at the open section 42,000. The discharge reported is about 190,000 cubic feet per second. This would indicate a velocity, an average velocity of about 4.9 feet for the International Bridge Section and about 4.5 feet for the Open Section.

For a discharge of 200,000 cubic feet per second, the aver-

age velocity at the International Bridge Section would be about 5.12, and at the open section about 4.75.

Q. Well now those sections checked with each other, did they?

A. On the average discharge from 1900 to 1907, the equations derived by the complainant from the gagings at these two sections, show a difference of about 2,700 cubic feet per second or a little over ¼ of 10,000 cubic feet per second.

Q. Expressed however in per cent. of the volume of discharge, within what per cent. would it be?

A. Slightly over one per cent.

Q. They check within slightly over one per cent.?

A. Yes, about 1¼.

Q. Now having in mind the facts to which you have heretofore referred in your testimony with reference to the physical conditions at the place of each of these sections, and the fact one was an open section and the other was a bridge section, and the other physical conditions, what does the fact as to the checking of these sections indicate to an engineer, as to the degree of credibility to be given to the work of the Government Engineers in this respect?

A. That so far as the performance of those labors which it was possible for the individual to perform, the work has been exceptionally well done; that whatever errors are present are inherent in both series of observations to practically the same extent.

Q. I wish to direct your attention to another element as affecting the accuracy of the work done in the measurement of these rivers, namely passing boats. That I think you have mentioned several times in your testimony as a disturbing factor, particularly in connection with the prosecution of some work done on the St. Marys River. What were the conditions so far as passing boats were concerned in the three rivers, the St. Clair, the Niagara and the St. Lawrence when they were measured, how did they compare?

A. The effect of passing boats in both the Niagara and the St. Lawrence would have been relatively insignificant. They would I think have been of importance on the St. Clair.

Q. In that respect then there were elements of advantage when the Niagara and St. Lawrence were measured, which were not present when the St. Clair was measured?

A. Yes, sir.

Q. Let us take the situation which was presented to the engineers in measuring the St. Clair River. Is there anything in the presence of Lake St. Clair and in connection with

the effect of Lake St. Clair upon Lake Huron—I mean anything in the presence of Lake St. Clair in the place it is, which injected into that situation an element of complexity which in your opinion was not present in the case of the measurement of either the Niagara or the St. Lawrence?

A. The presence of Lake St. Clair would have only a very limited, if any influence upon the measurement of the quantity of water passing. It has an important influence upon the connection of that quantity of water with the stage of lake to which it is related.

Q. That is the increment?

A. No, that is not the increment. That is with the establishment of the quantity of water which will be delivered for any given stage of lake.

Q. Does it not make the derivation of the increment of the St. Clair River a more difficult problem than it would otherwise be?

A. Than of the other two?

Q. Yes.

A. It does.

Q. It is a harder problem to derive the increment for the St. Clair, other things being equal, by reason of the presence of Lake St. Clair, than it would be to derive the increment of either the Niagara or St. Lawrence. That is an element of complexity that is not present in the other two problems?

A. It is the most serious element of complexity that is encountered in the entire investigation.

Q. Now were there any water gage troubles encountered in the measurement of the St. Clair which caused any difficulty in the measurement of that river?

A. Yes, there were.

Q. What were they?

A. The gagings originally were attempted to be referred to a gage at Fort Gratiot Light. This gage became choked up, the pipe connecting to the gage became choked up with sand, and it was necessary to transfer the reference observations to Harbor Beach, by means of a series of simultaneous observations upon the gage at Fort Gratiot and at Harbor Beach. The gage in Lake St. Clair appears to be of very questionable reliability on account of the inattention, apparently, of the gage reader there.

Q. So there was an element of uncertainty in the St. Clair problem which was not encountered in the case of either Niagara or St. Lawrence?

A. There is an element of uncertainty which was encountered in attempting to connect the gagings of St. Clair River to the lake elevations corresponding to them. Whether there were similar difficulties on the Niagara or the St. Lawrence, I am not informed. It is my impression that there were certain difficulties with the Buffalo gage.

Q. You say that is your—

A. That is an impression that I have. I will say that there has been certain difficulties with the Buffalo gage. Whether they were present during the observations or not, I am not certain, but I noticed that there were some changes of gages at that time, as shown by the gage records.

Q. So far as this Buffalo gage is concerned, you are not to be understood as indicating that you have any specific information of trouble of the kind mentioned by you, are you?

A. No, I simply say that I have seen references to trouble with the Buffalo gage at various times. Whether there was any trouble during these observations, I don't know, and I would anticipate that with the experience that had been had before, that if there were any such that they would have been looking out for such trouble and probably pretty promptly eliminated, if it had been discovered.

Q. That is by that you mean they lose a record of a day occasionally?

A. Well I do not recall specifically what the difficulty was with that gage, but I have known of criticisms of it from time to time.

Q. It was not a very serious difficulty, was it?

A. I don't know; it might or might not have been depending on its location. I could conceive that there might be some question as to whether the gage at all times represented the true surface elevation of Lake Erie in that location. That would, however, have no bearing upon the accuracy of the measurement of the quantity of water passing. Don't let us get confused on that point, that any criticism of a reference gage away from the section would have no bearing whatever on the quantity of water passing at the time the measurement was made.

Q. But it would have a bearing in deducing the law of discharge of the river?

A. It would have a very important bearing on that.

Q. Now I understand you to say that it has been your view in the study which you have made of these observations that the reason for rejecting the law of discharge which flows from

the observations as a mathematical proposition is that Lake Erie at Buffalo is so capricious that it does not remain steady long enough to secure good results in gaging. I understand that to be true?

A. That is an element and an important element.

Q. Well, is it the most important?

A. If you change the word "capricious" to "unstable", I think it would come more clearly conveying the meaning.

Q. That is to say your reason for rejecting the conclusions which necessarily flow from the Niagara observations is that in your view Lake Erie at Buffalo is unstable.

A. That is one reason.

Q. I gathered from your analysis of these figures that that was your prinicpal reason?

A. No, I don't think it is. I think there are other reasons that are as potent.

Q. Well, that is a reason?

A. That is a reason and a strong reason.

Q. You give great weight to that?

A. I do.

Q. In arriving at the conclusion that the same use cannot be made of the observations of the Niagara River as are made of those of the St. Clair and the St. Lawrence?

A. (No response.)

Q. How did you get that impression that Lake Erie at Buffalo was so unstable that it did not remain steady long enough to secure good results in gaging?

A. From its performances at Buffalo, and from its performances at the other end of the lake at Amherstburg. The rise at Buffalo must be followed by a fall at Amherstburg, when the gage at Cleveland remains at the same elevation, and the changes of level at Amherstburg have been sudden and unexpected many times.

Q. Is it your opinion that the elevations of Lake Erie at the head of the Niagara River governed the outflow of that river?

A. Not entirely.

Q. Does it have anything to do with it?

A. Considerable.

Q. Is it a principle factor in determining the outflow of the river?

A. Ordinarily.

Q. By ordinarily you mean what?

A. I mean under ordinary circumstances.

Q. Under ordinary circumstances. That is to say any other circumstance is an exceptional circumstance?

A. Yes.

Q. What are the other circumstances when the volume of water going through the Niagara River is not controlled by the elevation of Lake Erie?

A. By the elevations of Lake Erie where?

Q. At the head of the river.

A. In cases of variable barometric pressure along between the two ends of the lake.

Q. Which lake is this, Lake Erie?

A. Between the two ends of Lake Erie; that is, I could conceive of a barometric pressure at the lower end of the lake, with a lighter one at the upper end, which would cause a tilting of the water in Lake Erie, independent of wind effects, in which the discharge would be larger for the lowered elevation at the east end of the lake than would normally occur there.

Q. Is this purely theoretical, or is that based upon some study which you have made of that subject?

A. Well, it is based upon the well known laws of physics.

Q. Why is that true, in your opinion?

A. Because the pressure producing the discharge is not only the pressure of the weight of the water itself, but pressure of the superincumbent air, and if the pressure of the air changes and the pressure of the water did not change, the effect would be to force out more water. Now if the pressure of the air changes, to maintain a uniform pressure, the pressure of the water must decrease, in other words the water must drop, and consequently measuring your forces producing discharge by the elevation of the surface of the water would cause an apparently lower discharge than might actually be taking place, and conversely.

Q. Is it not a fact that the air column at the Buffalo gage, or at the head of the Niagara River is balanced by the air column in the river two miles below, as at Austin street, and that it is therefore eliminated in causation of flow?

A. That is not necessarily so. Observations which I have made barometrically have indicated to me that where you come in from a broad open reach into a constricted area, particularly such as exists in the neighborhood of a large city where buildings obstruct the free passage of air, that there may be quite sudden and appreciable barometric changes or differences of barometric pressure at the same time, and it is entirely possible that the barometric pressure at Austin street, or even at the International Bridge, might be appreciably different from that at the foot of Lake Erie.

Q. What is your view as to the limit of the variation produced by this cause, which you have just specified?

A. Why it might easily amount to as much as .05 of a foot.

Q. .05 of a foot?

A. Yes.

Q. What percentage of the volume of discharge would that be?

A. About ¾ of one per cent.

Q. Now that is a factor, if I understand the situation that is just as likely to be on the one side as on the other, so that over a period of time there would be a tendency to balance, would there not?

A. Yes. It is not an important consideration, but when you ask the broad general question, I think that it points—

Q. I want some other factor you have in mind as indicating to you as an engineer that you cannot deal with these Niagara observations in the same way as engineers deal with the St. Clair and the St. Lawrence, besides this barometric pressure condition?

A. Well, the barometric pressure condition would apply to the other observations, to some extent at least.

Q. That is to both the St. Clair and the St. Lawrence?

A. Both the St. Clair and the St. Lawrence, probably less to the St. Lawrence than to the St. Clair.

Q. It would be a greater factor at St. Clair than Niagara, wouldn't it, on account of the greater distance between Lake Huron and Lake St. Clair?

A. I would be in doubt about that on account of the question of the elevation of the land and the height of buildings coming in. I think that it is the obstruction by elevations of free flow of the air back and forth that has considerable to do with these changes of barometric pressure that you get on occasions.

Q. You do not regard this as a particularly important factor, as distinguishing the Niagara from the St. Clair and the St. Lawrence?

A. Not at all.

Q. What influence on the discharge of the Niagara River does the elevation of the water at the west end of the lake have, that is to say at Amherstburg?

A. Not very much.

Q. Does it have any?

Mr. Adcock: You mean the elevation different from the elevation at the other end?

Mr. Wilkerson: With the lake tilted up.

A. When the lake is covered with ice, it might have an influence.

Q. We are speaking about the open season, aren't we in this case?

A. Oh, I didn't know that you were,

Q. Now as a matter of fact isn't it a statement of the fact, a statement of a correct fact to say that the flow through the Niagara River is governed by the elevation of the lake at the head of the river?

A. That is substantially accurate, and accurate enough for all practical purposes.

Q. Why did you put in the tables showing an increment derived from the mean of the observations taken at Amherstburg and Buffalo?

A. Because the elevations of Lake Erie upon which discharge is computed is referred to the mean elevation of the lake; that is in all the discussions of the effect of the increment, we have been dealing with the lowering of the lake as a whole, and the true elevation of Lake Erie cannot be represented by any single gage, but requires at least four. We have only three, Buffalo, Cleveland and Amherstburg. The mean elevation of the east and west ends of the lake is perhaps as near an average elevation of the lake as is a gage on the south side of it, and is certainly nearer to a mean elevation than a gage at one end.

Q. But in a series of observations taken over a number of days, the observations at Buffalo must control, do they not?

A. Yes, must control, except that that is not a sufficient control, for the reason that we should also know what the elevation of the lake is on the Canadian shore; that for an accurate comparison we should have the relation between the elevation of the lake at the Buffalo side and at the Canadian side, as there may be appreciable variations between the two sides.

Q. You mean for the control of a single observation, or are you considering water level?

A. I am considering connecting the discharge with the elevation of the lake, whether it be for a single observation, or a series.

Q. At Buffalo?

A. Buffalo or anywhere else; that an observation taken on one side of the lake is not a sufficient establishment of the elevation of the lake controlling discharge to lead to an accurate determination.

Mr. Adcock: Of the increment?

A. No, the relation between discharge and stage.

Mr. Wilkerson: Are you aware of the fact that under the supervision of the Deep Waterways Commission there was a gage maintained on the Canadian side as well as on the American side?

A. I recall that there were gages on the Canadian side of the river during some of the work of the Board of Engineers on Deep Waterways.

Q. And are you aware of the fact that they corresponded so accurately that as a result of the experiment, it led to the abandonment of one of them?

A. I am not aware of that fact. I am not surprised that it has been abandoned, but even with the experience that might have been gained in a short period of time such as that covered by the observations of the Board of Engineers on Deep Waterways, it does not seem to me to be conclusive.

Q. Have you ever examined the observations?

A. I have not.

Q. Made any study of them?

A. I have not, of the comparison of those two gages.

Q. Do you know the period over which they were taken?

A. I do not, but I know the period during which the Board of Engineers on Deep Waterways were in operation, approximately.

Adjourned to Tuesday July 22, 10 a. m.

Tuesday, July 22, 10 a. m.

GARDNER S. WILLIAMS, resumed the stand for further cross-examination by Mr. Wilkerson and testified as follows:

Q. We were speaking yesterday about the checking of different cross-sections of a river, and with reference to what is meant by the instability of a river. You expressed your opinion that the Niagara River was too unstable to be dealt with in the way in which engineers generally deal with rivers in this respect. Did you have in mind a statement appearing on page 284 of the report of the Board of Engineers on Deep Waterways, part 1? I direct your attention specifically to the page which I have indicated, and read the following:

"In connection with the direct observations made to determine the outlet from the lake at different stages, continuous

readings were made of the gages from which the slope of the foot of the lake and the river surface has been computed for the corresponding volume of discharge, which with the carefully measured cross-sections of the river shown on plate 8 y furnishes a check on the equation of discharge given above and shows a discrepancy of less than 3 per cent. for maximum volume of outflow used in this discussion''?

A. I am not aware that I expressed the opinion that the Niagara River itself was too unstable. I did express the opinion that the variation between Lake Erie and the Niagara River was too unstable, and I still maintain that conclusion.

Q. In your opinion, why is it that the relation of the discharge of the Niagara River and Lake Erie is such that the law of discharge cannot be derived?

A. The first reason is on account of the instability of Lake Erie. In order to create the flow through the Niagara River that corresponds to any stage or elevation of the surface of Lake Erie, time must be given for the river to be affected clear to the Falls.

Lake Erie does not remain in one position long enough for this effect to take place, or if it does it is only on very rare occasions.

A second reason is that when Lake Erie rises at Buffalo it almost—when it rises as the effect of winds on account of which it is vibrating daily almost, as the plottings in exhibit, William's Exhibit 35, chart 4, will show, wherein are plotted the gage readings at Buffalo daily, as derived from William's Exhibit 29, there is presented graphically the fluctuations of the surface of the lake at Buffalo. Now when the water rises at Buffalo and lowers at Amherstburg, that rise at Buffalo is caused by a flow towards Buffalo along the surface of the lake created by the action of the wind. At the same time there is a counter flow from Buffalo towards Amherstburg through the lower portions of the water; during the time that the lake is rising, the flow towards Buffalo necessarily is greater than the flow back towards Amherstburg, but at the moment that the lake becomes stable in any position the flows in the two directions, are for the time being, alike. As the lake at Buffalo begins to fall, the flow towards Amherstburg increases.

Now, it does not take an elaborate computation to show that the velocity of flow towards Amherstburg to be observed at such times and with such differences of elevation, as have frequently occurred between Buffalo and Amherstburg; the flow away from the mouth of the Niagara River is greater than the

flow into it. At those times the discharge—I should say the velocity of flow away from the mouth of the Niagara River is greater than the velocity into it. At those times the discharge for the Niagara River, while corresponding to the high stage of the lake, will necessarily be less than they would be were the lake at that elevation throughout its entire area.

Consequently, a considerable proportion of the measurements of discharge of the Niagara River at the higher stages give a discharge lower than those which naturally belong to the elevation of the lake to which they are alleged to correspond. This is outside of the fact that the discharge of the river does not come to that corresponding to the elevation of the lake for some considerable time after the lake has risen to the point, as it is necessary to fill a prism extending from the Falls to the entrance to the lake with water, the base or upper end of which is the change of elevation of Lake Erie; the lower end is zero and the area is the area of the surface of the river between the outlet of Lake Erie and Niagara Falls before the conditions of flow corresponding to that elevation of the lake are established.

Q. By that you mean that a velocity of approach enters in the movement of Lake Erie towards or from the river?

A. A velocity both of approach and of departure.

Q. In your opinion what is the measure of that velocity?

A. The measure of that velocity would be the volume of water which changes ends of the lake and the space through which it has to pass in that motion.

Q. What in your opinion is the velocity, say within a mile of the head of the river?

A. Within a mile of the head of the river, that is a matter of computation. It would be the volume of water which passes the section a mile from the river divided by the area through which it passes.

Q. Have you any opinion as to how much it would be?

A. It will vary greatly because sometimes the differences of elevation between Amherstburg and Buffalo are zero, frequently they are .6 of a foot, not for long periods; not infrequently they are more than a foot. On occasions during which observations were made, they have been something over three feet; and there are records, I am informed, of a difference of elevation between Buffalo and Amherstburg approaching 12 feet.

Q. That is sometimes one is higher and sometimes the other is higher?

A. Yes.

Q. Those are things that in the long run, one practically neutralizes the other?

A. That is correct. If you should take observations every day for a long period of time and refer them to the Cleveland gage and the observations were accurate, it would be possible to get an increment of Lake Erie that would be applicable in this case; but it is not possible by a reference to the Buffalo gage unless the observations should extend over a very much longer period of time.

Q. With Amherstburg one foot below Buffalo, in your opinion what volume of discharge would be added to the Niagara River?

A. That being the stable condition? That being the condition, having arrived at that condition you mean?

Q. One of these derivation conditions?

A. Lake rising or lake falling?

Q. Would it make any difference? Give both the rise and fall.

A. It would make a difference; if it is falling the tendency would be to decrease the discharge. If it is rising the tendency would be to increase it to a less extent.

Q. Well, take the case where the rise at Buffalo was within the last two hours preceding the taking of the observation.

A. A rise of a foot at Buffalo and a fall of a foot at Amherstburg?

Q. Where Amherstburg is a foot below Buffalo?

A. Where Amherstburg is a foot below? I should have to have some cross sections of the lake, in order to make that computation; but I wish to assure you that it is a figure well worth consideration, in dealing with this problem.

Q. Have you made any study of the Niagara observations for the purpose of determining whether the effect of a rising stage is shown in the discharge measurement?

A. I have not, any very extensive one.

Q. And from such examination as you did make, what was the conclusion at which you arrived?

A. I arrived at no conclusion from that examination, except that it is probable that the measurements are too inaccurate to represent these conditions.

Q. Did you not make any attempt to find that in the observations?

A. I have not, specifically.

Q. Take these observations during the two periods which are under consideration, 1899 to 1900 and 1907 to 1908, as I

understand it, how many times does it appear from those observations that there was a rise of as much as a foot at Buffalo within two hours?

A. As far as I recall, I have seen no data which would give that information.

Q. I direct your attention to hourly water levels as recorded by the self-registering gage at the United States Lake Survey, Buffalo, New York, during the months of June, July and August, 1908. I wish you would take those tables and state for each day what the variation in level is, and how much the variation for each day is from the mean level for the particular day, as indicated on the table?

A. I do not see that that information is in the tables here in such form as to be gotten readily. It will take some time to get what you want, as it involves both a searching through the columns here, if I understand the table, of 24 readings each day, and a subtraction from the mean; and it is a thing that any clerk can do. I have no reason to question the record here, or criticise it.

Q. I show you a document in three parts, consisting of three sheets, being marked table XLVII, 1, 2, and 3 respectively. They purport to be certain figures of the United States Lake Survey, Preservation of Niagara Falls, Elevation of Lake Erie, derived from discharge of Niagara River, International Bridge, Buffalo, New York, for the years 1907 and 1908, during the months of October and November, 1907, and June, July and August, 1908; and I ask you to state what appears on this table with reference to the change of lake level during the measurements; and in connection with the question, I ask the Commissioner to mark this Williams' Exhibit Cross Examination Number One; the same being the document referred to on page 473 of the record as one of the tables furnished to the counsel for the defendant.

Mr. Adcock: Counsel for the defendant state that they have no record or recollection of having or receiving the table.

Mr. Wilkerson: There is also a reference to this table in the plate which was introduced in evidence by the Complainant, based upon these Niagara River observations.

Mr. Adcock: I do not believe that is shown on the plate introduced in evidence. That has a reference to the table, but there is a statement that there were observations made in 1907 and 1908 on that plate referred to.

The Witness: You want an answer so this may be put in the record?

Mr. Wilkerson: Yes.

The Witness: Columns 5 and 6 of Williams Exhibit Cross Examination Number 1, purport to show the change of lake level during measurement for the several measurements which are identified by date in column number 2 and by number in column number 1, being measurements of the discharge of Lake Erie taken during the years 1907 and 1908.

Column 5 purports to give the rise in feet of lake level during the measurement and column number 6 purports to give the fall in feet during the time of measurement.

Mr. Wilkerson: I think you might as well incorporate this whole table in the record at this point, so there will be no misunderstanding about it.

U. S. LAKE SURVEY

PRESERVATION OF NIAGARA FALLS, ELEVATION OF LAKE ERIE, DERIVED FROM DISCHARGE OF NIAGARA RIVER, INTERNATIONAL BRIDGE, BUFFALO, N. Y.

Number	Date 1907	Wind		Change of Lake Level During Measurement		Fall Lake Erie to Bridge Feet	Meter	Discharge Cubic Feet Per Second	Lake Erie Elevation Feet		Difference Feet	
		Direction	Estimated Velocity Miles	Rise Feet	Fall Feet		U. S. L. S.		Computed	Observed	Lake High	Lake Low
a	b	c	d	e	f	g	h	i	k	l	m	n
1	Oct. 21			0.02	0.13	4.95	2B	224070	573.26	572.98		0.28
2	22	S. W.	25	0.14	0.00	4.94	2B	225850	573.34	573.12		0.22
3	22	S. W.	30	0.09	0.07	5.03	4A	235600	573.75	573.54		0.21
4	22	S. W.	10	0.03	0.41	4.93	1B	225700	573.33	573.37	0.0'	
5	23	N. W.	25–30	0.13	0.26	4.71	1B	202510	572.26	572.42	0.16	
6	23	N. W.	30	0.29	0.01	4.75	1B	202870	572.27	572.39	0.12	
7	23	N. W.	30–20	0.21	0.02	4.86	2B	211320	572.67	572.61		0.06
8	24	N. W.	6	0.08	0.04	4.93	1B	212030	572.70	572.66		0.04
9	24	N. W.	6	0.00	0.16	4.85	2B	215140	572.84	572.57		0.27
10	24	S. W.	8	0.01	0.11	4.84	2B	209230	572.57	572.54		0.03
11	24	S. W.	10	0.16	0.07	4.84	1B	207170	572.47	572.41		0.06
12	25	N. W.	15–30	0.00	0.38	4.58	1B	205550	572.40	572.57	0.17	
13	25	N. W.	20	0.12	0.01	4.71	2B	198900	572.10	572.35	0.25	
14	25	N. W.	20	0.31	0.00	4.78	2B	207120	572.48	572.54	0.06	
15	26	N. E.	6	0.02	0.07	4.87	2B	205470	572.40	572.49	0.09	
16	26	N. E.	6	0.16	0.04	4.86	1B	208220	572.53	572.48		0.05
17	26		0	0.06	0.14	4.65	1B	196450	571.99	572.10	0.11	
18	26		0	0.02	0.24	4.60	2B	190050	571.72	571.94	0.22	
19	28	N. W.	35	0.03	0.32	4.61	2B	208370	572.53	572.48		0.05
20	28	N. W.	35	0.07	0.08	4.51	1B	196210	571.98	572.13	0.15	
21	28	N. W.	35	0.05	0.02	4.69	1B	204220	572.33	572.35	0.02	
22	28	N. W.	35	0.32	0.00	4.90	1B	211430	572.67	572.63		0.04

23		29	N. W.	10	0.10	0.04	4.92	1B		213770	572.78	572.82	0.04	
24		29	N. W.	20	0.03	0.15	4.76	2B		210540	572.64	572.64	0.00	0.00
25		29	N. W.	25	0.04	0.29	4.74	2B		212070	572.70	572.56		0.14
26		30	N. E.	3	0.14	0.08	4.85	2B		212380	572.72	572.44		0.28
27		31		0	0.06	0.06	4.84	2B		214080	572.80	572.45		0.35
28		31	N. W.	2	0.02	0.10	4.81	2B		208650	572.54	572.38		0.16
29		31	S. E.	3	0.08	0.16	4.67	2B		201650	572.22	572.19		0.03
30	Nov.	1	S. E.	10	0.13	0.10	4.57	46A		208330	572.53	572.32		0.21
31		1	S. E.	10	0.15	0.07	4.81	46A		211080	572.66	572.40		0.26
32		1	S	2	0.04	0.09	4.77	46A		210220	572.62	572.39		0.23
33		1	S.	2	0.05	0.10	4.78	46A		209780	572.60	572.38		0.22
34		2	S.	40	0.33	0.07	5.04	46A		219360	573.04	572.80		0.24
35		2	S.	40	0.03	0.23	4 99	46A		216660	572.92	572.84		0.08
36		2	S.	40	0.02	0.30	4.80	46A		207810	572.50	572.55	0.05	
37		4	W.	4	0.09	0.01	5.01	46A		224720	573.28	573.00		0.28
38		4	W.	4	0.12	0.20	4.85	46A		213380	572.76	572.87	0.11	
39		4	W.	7	0.15	0.02	4.79	46A		213230	572.76	572.81	0.05	
40		4	S. W.	10	0.04	0.23	4.94	46A		218840	573.02	572.93		0.09
41	June	26	S. E.	4	0.00	0.26	4.96	14B	1	228820	573.46	573.39		0.07
42		27	S. W.	3	0.12	0.01	5.17	14B	1	219030	573.03	573.28	0.25	
43		27	W.	5	0.07	0.03	5.23	1B	1	229760	573.51	573.49		0.02
44		27	W.	5	0.08	0.10	5.20	1B	1	227780	573.42	573.48	0.06	
45		29	W.	8	0.39	0.15	4.90	1B	1	225460	573.32	573.32	0.00	0.00
46		29	S. W.	7–20	0.10	0.22	4.97	1B	1	227050	573.39	573.39	0.00	0.00
47		30	S. W.	8	0.15	0.17	5.11	14B	1	239770	573.94	573.71		0.23
48		30	S. W.	7–12	0.08	0.37	5.05	14B	1	236730	573.80	573.60		0.20
49		30	S. W.	15	0.16	0.24	4.99	1B	1	221500	573.15	573.40	0.25	
50		30	S. W.	10	0.14	0.15	4.95	1B	1	219980	573.08	573.28	0.20	
51	July	2	E.	5	0.07	0.16	4.85	14B	4	213620	572.77	572.92	0.15	
52		2	N. E.	6–25	0.18	0.07	4.88	14B	4	218670	573.02	572.91		0.11
53		2	N. E.	15	0.06	0.14	4.89	1B	1	208410	572.54	572.85	0.31	
54		2	N. E.	20–7	0.03	0.17	4.88	1B	1	211690	572.69	572.77	0.08	
55		6	S. W.	15	0.06	0.09	5.04	14B	4	230740	573.54	573.52		0.02
56		6	S. W.	12	0.00	0.27	4.96	14B	4	220380	573.10	573.34	0.24	
57		6	S. W.	10	0.03	0.17	4.90	1B	1	240590	573.11	573.23	0.12	
58		6	S. W.	15	0.21	0.12	4.85	1B	1	217380	572.95	573.07	0.12	
59		7	S. W.	18	0.12	0.03	5.15	14B	4	222100	573.17	573.54	0.37	
60		7	S. W.	18	0.08	0.19	5.20	14B	4	230400	573.53	573.54	0.01	
61		8	N. W.	38	0.51	0.11	5.25	15B	1	239400	573.92	573.80		0.12

U. S. LAKE SURVEY—Continued

PRESERVATION OF NIAGARA FALLS, ELEVATION OF LAKE ERIE, DERIVED FROM DISCHARGE OF NIAGARA RIVER, INTERNATIONAL BRIDGE, BUFFALO, N. Y.

Number	Date 1908	Wind		Change of Lake Level During Measurement		Fall Lake Erie to Bridge Feet	Meter	Discharge Cubic Feet Per Second	Lake Erie Elevation Feet		Difference Feet	
		Direction	Estimated Velocity Miles	Rise Feet	Fall Feet		U. S. L. S.		Computed	Observed	Lake High	Lake Low
a	b	c	d	e	f	g	h	i	k	l	m	n
62	8	N. W.	38	0.00	0.66	5.00	15B 1	224320	573.27	573.46	0.19	
63	8	N. W.	10	0.12	0.07	5.18	15B 1	231060	573.55	573.63	0.08	
64	8	S. W.	25–40	0.20	0.13	5.06	15B 1	229470	573.49	573.54	0.05	
65	10	S. W.	6	0.04	0.06	5.23	1B 1	223380	573.23	573.30	0.07	
66	10	S. W.	6	0.09	0.07	5.20	1B 1	220520	573.10	573.27	0.17	
67	10	S. W.	6	0.01	0.04	5.15	15B 3	230220	573.52	573.30		0.22
68	10	S. W.	6	0.05	0.09	5.08	15B 3	222770	573.20	573.23	0.03	
69	16	S. W.	5–15	0.23	0.02	5.04	1B 8	229180	573.48	573.33		0.15
70	16	S. W.	8	0.02	0.11	5.03	1B 8	231750	573.58	573.39		0.19
71	18	S. W.	10	0.00	0.93	4.88	1B 8	234300	573.70	573.69		0.01
72	18	S. W.	10	0.00	0.31	4.69	1B 8	221470	573.14	573.21	0.07	
73	20	N. W.	4	0.00	0.21	4.83	14B 7	223100	572.22	573.24	0.02	
74	20	S. W.	8	0.06	0.13	4.77	14B 7	222480	573.19	573.10		0.09
75	20	N. W.	3	0.09	0.02	4.83	1B 8	222340	573.18	573.00		0.18
76	21		0	0.26	0.43	4.81	14B 7	216400	572.91	573.16	0.25	
77	21	N. W.	10	0.14	0.21	4.73	14B 7	213930	572.78	572.91	0.13	
78	21	N. W.	10	0.21	0.03	4.80	14B 7	215200	572.85	573.08	0.23	
79	22	S. W.	5	0.11	0.07	4.95	14B 7	228150	573.43	573.38		0.05
80	22	S. W.	12	0.10	0.02	4.94	1B 8	231250	573.56	573.42		0.14
81	July 22	S. W.	10	0.05	0.10	4.83	1B 8	224090	573.26	573.29	0.03	
82	22	N. W.	5	0.04	0.09	4.81	1B 8	226780	573.37	573.20		0.17
83	23	N. W.	5	0.16	0.08	4.80	1B 8	221610	573.14	573.00		0.14

84		23	N. W.	5	0.06	0.11	4.84	1B	8	221950	573.16	573.08		0.08
85		23	N. E.	8	0.13	0.14	4.83	1B	8	222880	573.20	573.12		0.08
86		23	N. E.	8	0.06	0.06	4.81	1B	8	222660	573.19	573.09		0.10
87		24	N. E.	5	0.06	0.03	4.78	14B	7	213120	572.75	572.84	0.09	
88		24	N. E.	5	0.14	0.12	4.80	14B	7	208520	572.54	572.87	0.33	
89		24	N. E.	12	0.15	0.65	4.70	1B	8	216060	572.90	572.85		0.05
90		24	N. E.	10	0.18	0.25	4.72	1B	8	212990	572.74	572.72		0.02
91		25	N. E.	4	0.14	0.12	4.86	14B	7	220410	573.09	573.20	0.11	
92		25	N. E.	6	0.15	0.19	4.72	14B	7	218340	573.00	573.00	0.00	0.00
93		25	N. E.	10	0.13	0.18	4.84	1B	8	225010	573.30	573.08		0.22
94		27		0	0.05	0.01	4.75	1B	8	221150	573.13	573.02		0.11
95		27	N. E.	3	0.05	0.02	4.76	1B	8	216700	572.93	573.00	0.07	
96		29	S. W.	5	0.06	0.05	4.81	14B	7	221010	573.13	573.10		0.03
97		29	S. W.	3	0.06	0.04	4.86	14B	7	226680	573.37	573.18		0.19
98		30	S. W.	8	0.02	0.07	4.85	14B	7	224840	573.29	573.21		0.08
99		30	S. W.	8	0.02	0.09	4.83	14B	7	221770	573.16	573.15		0.01
100		30	S. W.	10	0.10	0.03	4.83	1B	8	226800	573.38	573.15		0.23
101		31	S. W.	8	0.03	0.06	4.84	1B	8	227870	573.42	573.20		0.22
102		31	N. W.	15	0.00	0.03	4.81	1B	8	222820	573.20	573.20		0.00
103		31	N. W.	15	0.04	0.08	4.74	1B	8	223320	573.22	573.08		0.14
104		31	N. W.	15	0.12	0.00	4.78	1B	8	226370	573.35	573.11		0.24
105	Aug.	1	N. E.	10	0.26	0.01	4.90	14B	7	212960	572.74	572.67		0.07
106		1	N. E.	18	0.22	0.01	5.10	14B	7	221310	573.13	573.07		0.06
107		4	S. W.	15	0.04	0.28	4.79	14B	7	220370	573.09	573.18	0.09	
108		4	S. W.	15–8	0.09	0.07	4.82	14B	7	218710	573.02	573.18	0.16	
109		4	S. W.	15	0.17	0.03	4.76	1B	8	227110	573.39	573.06		0.33
110		4	S. W.	8	0.14	0.05	4.71	1B	8	225180	573.31	572.98		0.33
111		5	S. W.	8	0.64	0.06	4.98	1B	8	234750	573.72	573.39		0.33
112		5	S. W.	8	0.02	0.48	5.06	1B	8	237330	573.83	573.61		0.22
113		5	S. W.	35	0.25	0.80	5.05	14B	7	234570	573.71	573.77	0.06	
114		5	S. W.	20	0.30	0.47	5.02	14B	7	238630	573.89	573.88		0.01
115		6	S. W.	50	0.06	0.02	4.86	14B	7	233020	573.64	573.56		0.08
116		6	S. W.	20	0.00	0.69	4.71	14B	7	225050	573.30	573.27		0.03
117		6	S. W.	30	0.29	0.03	4.67	1B	8	213850	572.78	572.94	0.16	
118		6	S. W.	20	0.05	0.26	4.77	1B	8	217220	572.94	573.03	0.09	
					Means							572.586		

Mr. Wilkerson: Q. The figures to which attention has just been directed appear on pages 46, 47 and 48 of the document entitled "Preservation of Niagara Falls."

A. They do, but I am informed that the copy in the report "Preservation of Niagara Falls" has not been checked by the author of the table, and two typographical errors have been discovered in it up to the present time.

Q. What were they?

A. Errors as to the year in which the gagings at the bottom of page 46 and the top of page 47—

Q. That is to say observation numbered 41?

A. 41 was taken in 1908.

Q. And 46 was taken in 1907?

A. No, 46 was taken in 1908 also. The report shows all the observations that have been taken in 1907, whereas the major part of them were taken in 1908.

Mr. Adcock: Q. And I understand those inaccuracies were discovered by simply a casual reading of the exhibit, of the record?

A. They were called to my attention a moment ago by the principal witness for the Government.

Mr. Wilkerson: Q. How much time does it take ordinarily to make one of these observations?

A. I do not recall that that time has been specifically stated in any of the testimony regarding the Niagara River. Do you remember whether you stated it, Mr. Shenehon?

Mr. Shenehon: I do not remember whether I stated it. I know about the time.

The Witness: What I asked was whether there was a statement of it. My impression is about two hours.

Mr. Shenehon: That is right.

Mr. Wilkerson: Your understanding is that it takes about two hours to make one of the discharge measurements?

A. My understanding is that it takes about two hours to make one of the discharge measurements, according to the methods that have been used.

Q. Now this table number 47 to which I have directed your attention, identified as Exhibit 1, Cross Examination of Williams, shows the change of lake level during the time of measurement?

A. Yes, it purports to.

Q. And the same is true of Table Number 1, summary of discharges of International Bridge Section of the Niagara River, the observations were made in 1898 and 1899?

A. It was regarding that latter table that I was testifying, but the statement is true in regard to both.

Let me make a suggestion that may simplify reference to these exhibits, unless you specially desire to have that exhibit identified, that is to have it as number 1, why not let it appear consecutively in my testimony, and you can enter a note that the exhibit is introduced in cross-examination, beginning with number so and so.

Mr. Wilkerson: We will have to get the matter of numbering these exhibits straightened out. It appears to be an exhibit which apparently was produced at the taking of the Government's direct testimony, and it was stated that it was part of the information which was furnished to the defendant; so properly it goes into the record as one of our exhibits.

Now, for convenience, in connection with your testimony, I have referred to it as Exhibit number 1 in your cross-examination, but we will have to give it a number when we come to print this record; it will have to be numbered as a Government exhibit. We will have to go through the exhibits and arrange them in that way because it is really one of our exhibits.

Mr. Adcock: It is absolutely confusing, the way those exhibits are in there; tables and so forth all mixed up, A, B, C and so on, and there is no way of arranging them.

The Witness: They were only marked for identification. There were I think seven exhibits put in by the Government in their direct testimony if I remember right.

Mr. Wilkerson: Q. Referring to these Niagara River observations, and to the column which indicates the change of the lake during the time of making the observation; let us take the first observation that appears in the 1898 observations: Measurement number 5 September 10, 1898, shows that during the time of the measurement the lake rose .02 of a foot, and fell a little more than .2 of a foot?

A. That is correct.

Q. And taking number 6 observation made on the 13th of September, 1898, that shows that during the time of the measurement there was a rise of .06 of a foot and a fall of .22 of a foot?

A. That is corerct.

Q. Take observation number 7, the same being made on the 13th day of September, 1898. That shows no rise, and a fall of .21 of a foot?

A. That according to this record was on the 13th.

Q. The 13th of September, 1898?

A. No rise, and a fall of .21.

Q. And observation number 8 for September 15, 1898, shows a rise of .07 and a fall of .11?

A. Correct.

Q. And number 9 for September 15, 1898, shows a rise of .44 and a fall of .02?

A. Correct.

Q. And number 10 for the 17th of September, 1898, shows a rise of .06 and a fall of .15. Number 11 for September 17, a rise of .18 and a fall of .06. Number 12 for September 20th, shows a rise of .13 and a fall of .20. Number 13 for September 20th, 1898, shows a rise of .15 and a fall of .06. Number 14 for September 22, shows a rise of .02 and a fall of .12?

A. You said the 15th or 14th?

Q. 15th.

A. Number 15 shows a rise of .25 and a fall of .07 according to this.

Q. Number 14 is the last I read.

A. I misunderstood. I thought you said 15, and that is what I caught here.

Q. Considering this table as a whole, Mr. Williams, what in your opinion does it indicate to an engineer as to the stability of the lake during the larger portion of the periods covered by these observations?

A. Understanding by "periods covered by these observations" to mean the time elapsing between the moment of beginning and the moment of closing a single observation of discharge, it shows that the lake was reasonably stationary at that time.

Q. Would you say the same thing with reference to the observations which are set down in what has been called table XLVII, the same being the observation on "Preservation of Niagara Falls" for the years 1907 and 1908?

A. Without a minute examination of the table I can't say that that is so. There should be an exception made in regard to certain observations in both tables, where the rise and fall becomes an appreciable factor, or at least is larger than I would consider represented stable conditions; as for example observation 113 of William's Exhibit 1 on Cross Examination Number 1, where there is a rise of .25 and a fall of .8. That is followed by one the same day, wherein the rise was .3 and the fall was .47.

Also a few of those observations in William's Exhibit 24,

as notably observation 58 on November 9, which shows a rise of .45 and a fall of .27; observation 62 on the 10th shows a rise of .67 and a fall of .03.

These are rather exceptional and considering the series as a whole I would say that the stage of the lake, the elevation of the lake was reasonably constant during the observations of discharge.

Mr. Adcock: You mean during the time—

A. During the actual time the observation of discharge was being made.

Mr. Wilkerson: Q. Referring specifically to observation number 113 in table number XLVII William's Exhibit on Cross Examination number 1, and directing your attention to the last two columns of the table relating to that observation, I will ask you whether it is not a fact that observation appears to be consistent with the other observations appearing in the table?

A. Let me have that exhibit will you please until I see if this is an actual transcript (examining same).

Q. (Question read.) A. So far as the comparison shows between a computed elevation of the lake based upon a discharge equation and the observed elevation of the lake, I see nothing to particularly mark this observation from the other. In fact the coincidence of the two quantities, the computed elevation and the actual elevation is closer than in several others of the series.

Q. You referred to one or two others, which you refer to as being rather exceptional. What did the table show with reference to those, as to their being consistent with the other observations?

A. To answer your question specifically, the other observation referred to in this table was number 114. I do not find that similar information is given in regard to the previous measurements, but so far as observation number 114 goes, the coincidence is even closer, very much closer, than in observation 113. I would say however that I do not wish my answer to the previous question to be misunderstood. The question that was asked me was whether those elevations given in this table indicated a stability of the lake surface during the measurements. Now, to my mind, the instability of the lake surface during the particular hours of the measurement can be quite readily corrected, the stability or instability can be quite readily taken care of in the reduction of the observations, and I assume it has been.

Q. I call your attention to observations Nos. 57, 58, 60 and 61, and ask you to state what appears as to the change of lake during the measurements and also what appears as to the effect which the changing lake stage appears to have had upon the volume of discharge.

A. Observation 57 shows a rise of nothing during the observation; a fall of .46 of a foot.

Observation 58 shows a rise of .45 during the observation and a fall of .27. The elevation of the lake in observation 58 was .03 of a foot higher than in observation 57. The discharge was increased 1,600 cubic feet, which would indicate an increment of 53,000.

That elevation for observation 57 is given here as 570.11 and for 58 as 570.14. The discharge for observation 57 is given as 155,600 cubic feet per second, and the discharge for observation 58 is given at 157,200 cubic feet per second.

Mr. Adcock: Q. The difference is how much?

A. The difference I make 1,600 cubic feet per second. Dividing that by .03 seems to give 53,000 as the increment.

Mr. Wilkerson: Q. Is it your opinion as an engineer that increments can be derived in that way?

A. That, if the gaugings were accurate, that is the increment indicated by those two discharges. If the measurements were accurate, that is the increment of those two conditions.

Q. Well, is it your opinion as an engineer that engineers would take the derived increment from two observations, where there was a difference of only .03 of a foot in the level?

A. If the errors of the observation are as stated by the principal witness for the complainant, namely, something like 1 per cent., an increment so derived ought not to be in error more than the 1 per cent.

Q. Referring to the column at the extreme right of the table, with reference to these observations, what is the discrepancy as indicated by the percentage there shown?

A. Well, I don't know what that percentage represents. They are, opposite observation 57, minus 0.9, and opposite observation 58, minus 0.2.

Q. Does that indicate to you as an engineer whether or not the rising or falling stage has an effect upon the volume of discharge; and if so, what?

A. That shows on the face of it that the larger discharge occurs on the rising stage.

Q. By what per cent.?

A. Well, that depends altogether upon what the correct value of the increment is, and without knowing that I can't say. In the increments the value which was assumed in the complainant's equation, it is about 100 per cent. It affects the increment to the extent of about 100 per cent.

Recess to 3 p. m.

After recess, 3 p. m.

GARDNER S. WILLIAMS resumed the stand for further cross-examination by Mr. Wilkerson and testified as follows:

Q. You have the three plates that were submitted to you this morning?

A. Yes.

Mr. Adcock: You mean the photographs?

Mr. Wilkerson: I will ask you now to refer to the three copies of hourly water levels as recorded at Buffalo, during the months of June, July and August, 1908, which for the purpose of this question I ask to have marked "Williams Cross-Examination Exhibit 2," the same being three sheets, and ask you to state what those observations show with reference to the variation of the water level of Lake Erie, say, the difference between the maximum and the minimum and the variation from the mean at Buffalo.

(Document referred to in the question was marked Williams Cross-Ex. 2.)

BUFFALO GAGE.

COMPARISONS OF HOURLY READINGS.

June. 1908.	Maximum Less Mean.	Mean Less Minimum.	Maximum Less Minimum.
1	0.37	0.36	0.73
2	0.38	0.25	0.63
3	0.31	0.25	0.56
4	0.21	0.30	0.51
5	0.22	0.16	0.38
6	0.17	0.17	0.34
7	0.07	0.11	0.18
8	0.56	0.26	0.82
9	0.43	0.44	0.87
10	0.21	0.24	0.45
11	0.39	0.36	0.75
12	0.13	0.21	0.34
13	0.24	0.29	0.53
14	1.56	0.86	2.42
15	0.39	0.43	0.82
16	0.25	0.19	0.44
17	0.33	0.30	0.63
18	0.20	0.17	0.37
19	0.47	0.36	0.83
20	0.50	0.47	0.97
21	0.57	0.30	0.87
22	0.36	0.24	0.60
23	1.02	1.08	2.10
24	0.53	0.45	0.98
25	0.39	0.27	0.66
26	0.35	0.33	0.68
27	0.29	0.25	0.54
28	0.24	0.28	0.52
29	0.78	0.51	1.29
30	0.53	0.38	0.91

BUFFALO GAGE.

(Continued.)

COMPARISONS OF HOURLY READINGS.

July, 1908.	Maximum Less Mean.	Mean Less Minimum.	Maximum Less Minimum.
1	0.26	0.26	0.52
2	0.36	0.38	0.74
3	0.22	0.21	0.43
4	0.30	0.19	0.49
5	0.55	0.41	0.96
6	0.28	0.28	0.56
7	1.10	0.46	1.56
8	0.35	0.37	0.72
9	0.23	0.20	0.43
10	0.10	0.08	0.18
11	0.20	0.29	0.49
12	0.24	0.26	0.50
13	0.59	0.41	1.00
14	0.36	0.43	0.79
15	0.57	0.36	0.93
16	0.42	0.42	0.84
17	0.67	0.78	1.45
18	0.81	0.61	1.42
19	0.30	0.32	0.62
20	0.23	0.23	0.46
21	0.35	0.33	0.68
22	0.27	0.16	0.43
23	0.15	0.14	0.29
24	0.37	0.36	0.73
25	0.35	0.12	0.47
26	0.18	0.21	0.39
27	0.17	0.18	0.35
28	0.09	0.13	0.22
29	0.14	0.16	0.30
30	0.16	0.08	0.24
31	0.22	0.40	0.62

BUFFALO GAGE.

(Continued.)

COMPARISONS OF HOURLY READINGS.

August, 1908.	Maximum Less Mean.	Mean Less Minimum.	Maximum Less Minimum.
1	0.46	0.53	0.99
2	0.32	0.85	1.17
3	0.24	0.42	0.66
4	0.52	1.08	1.60
5	0.63	0.67	1.30
6	0.77	0.67	1.44
7	0.25	0.29	0.54
8	0.21	0.24	0.45
9	0.33	0.33	0.66
10	0.24	0.28	0.52
11	0.23	0.21	0.44
12	1.08	0.50	1.58
13	0.99	0.46	1.45
14	0.22	0.36	0.58
15	0.36	0.46	0.82
16	0.28	0.37	0.65
17	0.41	0.45	0.86
18	0.28	0.52	0.80
19	0.58	0.39	0.97
20	0.20	0.34	0.54
21	0.17	0.13	0.30
22	0.37	0.30	0.67
23	0.16	0.07	0.23
24	0.16	0.18	0.34
25	0.38	0.55	0.93
26	0.58	0.50	1.08
27	0.71	0.48	1.19
28	0.24	0.31	0.55
29	0.54	0.22	0.76
30	0.16	0.12	0.28
31	0.12	0.13	0.25

Mr. Austrian: Those computations, Mr. Williams, were made from Williams Cross-Ex. 2, were they not?

A. They were.

Q. And this document Cross-Exhibit 2, was handed to you for the first time this morning and those computations were made by your assistant during the noon recess?

A. They were.

Mr. Adcock: Have you given us the tables showing the hourly elevations during the remaining period of the gagings? I want the record to show that we make request on the complainant for those tables which we understand the complainant now has in his possession here at the hearing, and which we are advised by complainant's counsel supplement the three sheets known as Complainant's Exhibit 2, carrying readings for continuous periods much beyond those indicated on this exhibit. And the Government's counsel very courteously and kindly now hands to defendant's counsel the documents now called for.

Mr. Wilkerson: Just state, Mr. Shenehon, which ones of the tables were produced.

Mr. Shenehon: Photographs of the actual record of the United States Lake Survey for the Buffalo gage for the month of June, 1899, July, August, September, October, November, December of 1899, May, 1900 and June 1900.

Mr. Adcock: What are there left there?

A. July, 1900, October and November, 1907.

Mr. Shenehon: I haven't those.

Mr. Adcock: That is all you have at present, as I understand it.

Mr. Shenehon: Yes.

Mr. Adcock: Then we make a request for the similar tables covering the months which are not included in these tables.

Mr. Shenehon: I have some more: There is July, 1900, and May, 1899, October, 1907, and November, 1907. That is all.

Mr. Adcock: What months are not there?

A. We are then short July, August, September and October, 1898, January, February and March, 1899.

Mr. Shenehon: There are not any sheets of this kind for 1898. The gage was established February, 1899.

The Witness: Then there are similar records for February and March, 1899, which have not been furnished. Is that right, Mr. Shenehon?

Mr. Shenehon: We feel that February and March do not

enter into any gagings we are displaying in this case. That is open season flow. Of course there are gage records consecutive on that gage from the year 1900 to the present time, and still going on.

The Witness: Then the statement as I understand it is that this gage was established in February.

Mr. Shenehon: 1900.

The Witness: In 1899, wasn't it?

Mr. Shenehon: Yes, 1899, that is right.

The Witness: February, 1899, and there are no records of recording gage prior to that time.

Mr. Shenehon: That is my recollection.

The Witness: All right.

Mr. Wilkerson: As to the sheets which were submitted to you this morning, the same being three sheets marked Williams Cross-Examination Number 2, have you familiarized yourself with and given consideration to the facts relating to the subject about which inquiry was made this morning?

A. I have forgotten just what the inquiry was. If you will, inform me.

Q. The inquiry related to the range?

A. To what they indicated?

Q. The range of variation from day to day as shown by those sheets.

A. Do you wish me to enumerate the particulars, or give a summary?

Q. The figures of course now appear in the record?

A. Yes.

Q. I merely want to know whether you, the witness, have personally examined the results of that compilation, and have familiarized yourself with the facts shown?

A. I have to a moderate degree, yes.

Q. What do you find the maximum variation during any 24 hours to be?

A. I will give you the range of it in just a minute. The daily variation, as indicated by these scalings from the record of the recording gage varies from .18 for the 24 hours on the 7th of June, 1908, to 2.42 feet on the 14th of June; the change of 2.42 feet appearing in consecutive hours as did also a change of 1.24 feet on July 17th, a change of 1.16 feet on August 12th and of .89 of a foot on August 13th. A change of 1.44 of a foot occurred in two hours, that is between three consecutive hours, on July 7th, and a change of one foot

within two hours on July 13th, and numerous other smaller changes.

Q. How many days all together is covered by that?

A. Ninety-two.

Q. And for how many days do you find the variation more than a foot?

A. I will have to count them—15 days.

Q. How many days do you find more than a foot and a half?

A. Four.

Q. Now referring to table Number XLVII, being sheets marked Williams' Exhibit Cross Examination Number 1, on how many of the days where the variation was more than 1 foot were discharge measurements made?

A. 18 observations, which were taken on six days.

Q. That is 18 observations you say?

A. Yes.

Q. Out of a total of how many?

A. 78.

Q. 18 out of a total of 78?

A. 18 out of a total of 78, yes, sir.

Q. And as to the 60 other observations, the variation on the day on which they were taken was less than a foot?

A. That is correct.

Q. On how many of those days when the variations were more than a foot was the variation during the day time on the dates on which observations were taken?

A. I could not say without an examintaion of the table. That particular inquiry was not contemplated when these figures were prepared, and they do not give the information.

Q. There are only a few days. I will ask you to look at that, so that we can get it into the record now.

A. There is nothing on the chart to indicate what is noon. I think there should be a statement to show that is noon. A man might start them at midnight.

Q. The hours on these sheets are numbered from 1 to 24, commencing, as I understand it at midnight. Is that your understanding about it?

A. That is my understanding now.

Mr. Adcock: Subject to verifying that statement.

Mr. Shenehon: The first hour is one o'clock in the morning.

The Witness: I am so informed by the complainant's principal witness.

Mr. Wilkerson: With that in mind, answer the question.

A. Just what is the question?

Q. (Question read as follows: "On how many of those days when the variations were more than a foot, was the variation during the day time on the dates on which observations were taken.")

A. On five days covering 16 observations.

Q. So far as the element of the movement of Lake Erie is concerned, what is your judgment as an engineer of the effect of that upon the accuracy of the 60 observations, where there was a variation of less than a foot in 24 hours?

A. I don't see as the fluctuation of the lake had very much to do with the discharge observation; that is with the accuracy of the observation itself.

Q. That is to say the accuracy of the observation was not in your judgment materially influenced by that element?

A. That is my view of it.

Q. I think there has been submitted to you, Mr. Williams, and you have been asked to check the correctness of, certain computations in which the level of Lake Erie has been computed from the discharge measurements by means of a certain law, which is taken as the law expressing the relation between the level of the lake and the volume of the discharge; and you have also checked the elevation of Lake Erie as thus computed against the observed elevation of Lake Erie for the same time. I ask you to state, so that we may have it in the record, what was the law which was taken as expressing the relation between the volume and elevation of Lake Erie?

A. The law which was applied appeared to be the same and was certainly very similar to that presented on Complainant's Exhibit 3; being the discharge curve for the International Bridge Section of the Niagara River.

Q. Just look at it so as to make sure that it is the same law.

A. I did examine it. I say that it was very nearly, and it was assumed to be, and to all appearances was, very nearly.

Q. Substantially the same law?

A. So far as I was able to detect, and so far as the accuracy of the plotting could control, it evidently was the same law.

Q. Now, as to how many observations did you check the computation by which the elevation of Lake Erie was determined with reference to a given discharge?

A. 107.

Q. Over what range of lake elevations do those 107 observations extend?

A. The minimum of 570.03 to a maximum of 573.92.

Mr. Adcock: You have handed him something here; let us have that identified.

Mr. Wilkerson: I did not intend to put the whole memorandum in the record. The paper which the witness is examining is a memorandum, which shows the result of these computations. I think for the purpose of this inquiry it will not be necessary to put the whole computation in the record. I am merely going to have him state certain facts with reference to the computation which he has checked.

Mr. Adcock: I wanted to have a copy of that in our possession.

Mr. Wilkerson: You may look at it any time you want to.

Mr. Adcock: Will it be understood that we may have a copy?

Mr. Wilkerson: It will be understood you may have a copy of the memorandum, of any memorandum which the witness refers to, to refresh his recollection in testifying.

Mr. Adcock: All right.

Mr. Wilkerson: Q. Now, over what range of time do the 107 observations extend?

A. That I can't say. Have you got the dates in here? Substantially over the five years.

Q. Embraced by the observations which were taken on the Niagara?

A. The observations which were taken on the Niagara at the International Bridge Section.

Q. And used in this case?

A. Yes, sir. It does not however include all the observations, nor half of them.

Q. That is to say we have 107 observations taken out of 219?

A. That is correct.

Q. How nearly do you find that the elevation of Lake Erie as computed according to the law there stated corresponded with the actual elevation of Lake Erie, as measured at the particular time when the observation was taken?

A. On seven occasions, the computation agreed with the observed elevation of Lake Erie through the 100th place, which was as far as it was attempted to establish it.

Q. That is to say for two decimal places—

A. For two decimal places.

Q. It was zero?

A. Yes. The maximum error on the high side, that is the maximum amount by which the actual elevation of the lake

exceeded the computed elevation was .08 of a foot of the maximum—

Q. That is how much in inches? That is an inch?

A. This is feet.

Q. Approximately an inch, less than an inch?

A. .96 of an inch, slightly under an inch. And the maximum variation by which the computed elevation exceeded the observed elevation was also .08 of a foot.

Q. That is less than an inch, slightly less?

A. Just slightly less than an inch. The average variation was .042 on the one side, and .041 on the other.

Q. That is practically half an inch.

A. That is practically half an inch, slightly less.

Q. And there are about as many in which the computed observations were high—

A. There were 52 in which the lake was higher than the computed value, and there were 48 in which it was lower, and 7 in which they agreed.

Q. If you didn't know what the elevation of Lake Erie was in these 107 instances, how nearly would you be able to predict by the application of this law expressing the relation which we have under consideration the actual elevation of Lake Erie?

A. In all cases you would have predicted it within one inch. In approximately half of the cases you would have predicted it within one-half an inch.

Mr. Adcock: That is the Buffalo gage?

A. Yes, that is referring to the Buffalo gage.

Mr. Wilkerson: Referring to the Buffalo gage?

Mr. Adcock: That applies to these 107 observations?

A. Yes, applies to 107 observations.

Q. And as I understand it these 107 observations referred to are selected observations are they not?

A. I assume that they are.

Mr. Wilkerson: Q. So that if you took these 107 observations, and took the mean of the discharge observations, by the application of this law you would be able to predict the mean elevation absolutely, wouldn't you? It appears that you would be able to do so?

A. It appears that that would be the case. I do not see anything the matter with the mathematics of that.

Q. Now taking into consideration the range of these observations, nearly four feet, and the length of time over which they have extended, five different years, taking into consideration the fact that you would thus be able to predict

absolutely by the application of the law expressing the relation between volume of discharge and lake elevations which is here applied, what is your opinion as an engineer as to the conclusiveness of the law expressing that relation which has been applied?

Mr. Adcock: When you say "these observations" you refer to the 107?

Mr. Wilkerson: That is referring to the 107 at Buffalo?

A. As to mean relations between the discharge of the Niagara River at the Bridge Section and the elevations of the Buffalo gage under the conditions represented by these 107 observations, I would say that the law appears to be well established.

Q. Does it appear to you to be as well established for the upper end of the curve, that is to say for the higher water, as it does for the lower part of the curve, the lower water?

A. I don't think there is much if any difference.

Q. The one appears to be as well established—

A. The one appears to be as well established as the other.

Q. The one appears to be established with as great a degree of accuracy as the other?

A. Yes, I say I do not see any distinction between them, still referring to the 107 observations under discussion.

Q. You have spoken now in your testimony of the equilibrium of the river as one of the elements which has entered into the accurate determination of the law expressing this relation between volume of discharge and lake elevation. I wish you would state what you mean by the equilibrium of the river, as you have used the term, specifically the Niagara River.

A. I had forgotten just how I used it, at the present moment. Can you refer to the point where I did use it, whether it had any special significance.

Q. Is that one of the elements which you think enters into the determination of the accuracy with which this relation has been expressed?

A. What is the question?

Q. (Question read as follows): "You have spoken now in your testimony of the equilibrium of the river as one of the elements which has entered into the accurate determination of the law expressing this relation between volume of discharge and lake elevations. I wish you would state what you mean by the equilibriu mof the river as you have used the term, specifically the Niagara River?

A. I don't think I have used that term. I may have used

it; I will not be certain. I have in mind some sort of a definition of it at the present moment, but I would not want to give it here as referring to the use of it that I made the other day.

Q. Do you know what the relative fluctuations between the Buffalo gage and the Chippewa gage are?

A. I do not recall at this moment. Of course fluctuations at Chippewa would be expected to be materially less than they are at Buffalo.

Q. Do you think that a definite relation could be worked out as expressive of the relation that these fluctuations bear to each other?

A. I think it would be rather difficult on account of the rapidity of change at Buffalo. I think that anything that was worked out would show a less effect at Chippewa than actually would apply there for the Buffalo gage elevation.

That is, to state it this way, I think if you took the information you have and worked out that relation, and then it were possible to raise Lake Erie successively to the various elevations you have considered and hold it there, you would find a different relation existed between the Buffalo gage and the Chippewa gage.

Q. Are you familiar with the discussion of the slope relations of the Niagara River as set down in the document on the Preservation of Niagara Falls, the same being as I understand it a public document?

Mr. Adcock: The same being the one heretofore referred to.

Mr. Wilkerson: Senate Document Number 105, Sixty-Second Congress First Session?

A. I read that discussion some time ago. I can't say I would consider myself at the present moment familiar with it.

Q. If as a matter of fact a relation has been worked out which would enable you to predict with substantial accuracy from the elevation at Buffalo what the elevation was at Chippewa, would that indicate to you as an engineer that that relation had been established with satisfactory accuracy?

A. It would depend upon the amount of information that was used in establishing it. I can, of course, conceive of having a very large number of observations with varying quantity, where the effects of the excesses and the deficiencies may ultimately cancel each other, and you get to the effect of a true mean.

Q. I ask you to refer to page 41 of this document, Senate

Document 105, Sixty-Second Congress First Session, and direct your attention to the equations numbered 5 and 6 on that page?

A. (Referring to same).

Q. You have looked at those, have you?

A. Yes.

Q. I will ask you whether or not from an engineering standpoint, the check between the equation for 1906 and for 1906-7 is a substantially accurate and satisfactory one?

A. The variation in the computed elevation at Chippewa for elevation of Lake Erie at 573 seems to vary by about 1/10 of an inch.

Q. Between 1/8 and 1/10?

A. About 1/10 of an inch, and it would seem to be a very close check, and would indicate that the conditions covered in the two cases, or that the mean of the conditions covered in the two cases must have been very similar.

Q. By water leveling, can you pass from the Buffalo gage to the Cleveland gage?

A. If you have a sufficient number of the observations, with a reasonable degree of precision.

Q. Is it your opinion that we have a sufficient number of observations to pass from the Buffalo gage to the Cleveland gage?

A. I think with all that we have, we could.

Q. That is from the year 1887?

A. I think that ought to be sufficient.

Q. From that on to the present time. You think that should be sufficient for an engineer to do that?

A. That is you mean now in passing from one gage to the other, to say that—let's see if we understand each other: You mean by that to be able to say that the mean elevation at Cleveland corresponded with a certain mean elevation at Buffalo. But I doubt if we have enough observations to enable us to say that, when the gage at Buffalo reads, say 573, what the gage at Cleveland would read.

Q. Do we have enough observations to establish the ratio of fluctuations?

A. What do you mean by "ratio of fluctuations" in this question?

Q. The monthly mean.

A. For any month, you mean? That is from month to month? Yes, I think so. Wait a minute, hold on; I do not think that we have observations enough to be able to predict

from the monthly mean of the Buffalo gage what the monthly mean of the Cleveland gage is.

Q. For a season?

A. For a season you have, but I don't think that you have for a month.

Q. Having the observations for the season for Buffalo—or two seasons for Buffalo and Chippewa—can we establish that relation?

A. Can you establish what?

Q. The ratio of fluctuations.

A. As I said before, you can establish what the mean elevation of each gage is with reference to the other, but I question if you would be able to establish what the maximum elevation of one gage would produce on the other.

Q. Have you stated what the ratio of fluctuation between Buffalo and Cleveland is?

A. I think I have not.

Q. What is it?

A. I don't recall.

Q. Taking it for a single season, an open season?

A. Well, I should have to look at the gage records. I don't recall what the relative fluctuation at Buffalo and Cleveland is at all.

Q. Is it not a fact that it is unity?

A. Let us understand "fluctuation." I understand fluctuation to be the variation of elevation between the high and low of the gage. If we are understanding it the same, then my answer is correct, or at least I believe it to be. If you mean something else by fluctuation, then possibly my answer is not correct. If a thing fluctuates, we understand it to be vibrating back and forth. I don't know what the variation between high and low at Buffalo is, as compared with the variation between high and low at Cleveland.

Q. Well, can you establish the ratio, of annual or monthly mean over a term of years?

A. I don't think I got all of that question.

Q. (Question read.) That is to say over a series of months or series of years?

A. I think that taking the year as a unit, you can. I question if you can for any particular month.

Q. Isn't the lake substantially level?

A. Taking the year as a unit it is. If you take a month, I question if it is.

Q. With that understanding, isn't the ratio of fluctuations unity between Cleveland and Buffalo?

A. I don't understand your term "fluctuations." If at Buffalo the lake fluctuates 12 feet, and at Cleveland fluctuates three feet, it certainly is not unity.

Q. Take the same meaning that you had when you passed from Michigan-Huron to Erie, in your direct testimony.

A. That was the annual change of elevation; that was annual fluctuation, or other fluctuations from year to year over a long period of years.

I have already answered that question by saying that I thought you could establish it for a year; that I question if you could for a month.

Q. That is to say when Lake Erie is 571 over a term of months or years at Cleveland, it is 571 at Amherstburg or at Buffalo?

A. The average would be, I think.

Q. And the same for 572?

A. Oh, yes.

Q. Then the ratio must be unity?

A. Well, you are using the term "fluctuation" in a little different way. I would call them relation of stage rather than fluctuation.

Q. Well it follows then that if the relation between Cleveland and Buffalo is unity and the relation between Buffalo and Chippewa is .56, that the relation between Cleveland and Chippewa would be .56?

A. Just read that question.

Mr. Adcock: That is over a number of years.

The Witness: Over any time.

Mr. Wilkerson: Q. Over a period of months.

A. That is just a concrete fact there, that if the relations are so, then the things that are equal to the same thing are equal to each other. That is all there is to it.

Mr. Wilkerson: We will submit to you, Mr. Williams, between now and the next session, certain computations from which the Chippewa gage has been predicted from the gage at Buffalo, and checked with the gage as observed at Chippewa.

Adjourned to Wednesday, July 23, 1913, at 10 o'clock a. m.

Wednesday, July 23, 1913, 10:00 a. m.

GARDNER S. WILLIAMS, resumed the stand for further cross-examination by Mr. Wilkerson and testified as follows:

Q. In connection with these computations for the purpose of establishing the relation between the levels of the lakes and the volume of discharge of the lakes respectively, you made use of the method which is designated as the "Three Point Method," did you not Mr. Williams?

A. I never so designated it. I always called it the Center of Gravity Method.

Q. The Center of Gravity Method?

A. Yes.

Q. But it is the method—

A. The method that has been designated I think by the "Three Point Method" by some who use it.

Q. Where did you get that method?

A. I developed it out of my inner consciousness. I do not claim to be the originator of it, but so far as my use is concerned, I developed it myself. It is so simple, I assume many others developed it before me.

Q. Is it not in common use among engineers?

A. I don't know to what extent it is. It is an absolutely rational method based upon the fundamental principles of physics; and I don't know whether anybody else uses it or not.

Q. Do you know whether or not it is an accepted method among engineers?

A. I don't know whether—well, yes it is an accepted method, because it is an absolutely accurate method.

Q. Is it a generally accepted method?

A. It is accepted by anyone who has occasion to use it. It is the most accurate method of determining the line, the straight line which represents a series of observations, where all observations are given equal weight.

Q. In what technical publications is it described? I mean if as a student of mathematics I wanted to get some information about this method, where would I go to find some place where I could study it?

A. I do not recall at the present moment where it has been described. I think it will be found in some of the transactions of the American Society of Civil Engineers, and I think also in the Journal of the Association of Engineering

Societies, but I won't be sure as to the latter, whether it has ever been described there or not.

Q. By whom was the description written, if you remember?

A. I had in mind a paper of Mr. George H. Fenkell, but on second thought I rather think the method was not described there.

Q. Did you use it in the analysis of the pipe observations described in the transactions of the American Society of Engineers?

A. It was used there, yes.

Q. You used it?

A. I used it. In fact it was at that time that it was developed, as far as I was concerned.

Q. And Mr. Fenkell was in colaboration with you?

A. He was.

Q. Now on what process of reasoning does the validity of that method, in your opinion, depend?

Mr. Adcock: As applied to the proposition we have under consideration.

Mr. Wilkerson: No, I am speaking of this method, the method called the gravity method or the Three Point Method for deriving a relation between observations relating to two conditions?

A. On the theory of resultant force of a system of forces.

Q. Why do you have three points? Why aren't two enough?

A. Because you have to have three in order to make the division at the intermediate center of gravity to give the observations all equal weight. If you divided them arbitrarily, you would not be giving them all equal weight.

Q. If you should take your observations and divide them into two groups with the same number of observations in each group, would you not as a matter of fact get a line as accurately, to say the least, as you would if the result of that division of observations was to give the groups in which there would be an unequal number of observations in the respective groups?

A. I think not. When considering the moments which the various observations have about the center of gravity. The first thing that we do is to balance the entire series of observations about a point. That point then divides the groups, divides the observations into two groups. And we then find the straight line through the centers of gravity of those two groups. Thereby we get a mathematical balance; that is

we balance the whole system first about the center of gravity, and then balance each end about its center of gravity.

Q. You think the result arrived at by grouping the observations, whether you would have more observations in the one group than another, would be essentially a more accurate result than if the observations were divided into two groups, each containing the same number of observations?

A. I think that when the observations are divided by a line passing through the center of gravity for the whole group, at right angles to the direction of inclination of the average line that the division gives the most accurate process of determining the mean line that can be derived.

Q. You have spoken of the weight of the observations as referred to the distance from the center of gravity of the whole system. Doesn't that in your opinion mean that the range of observations in a given state in lake stage very greatly increases the weight of the observations, or the conclusions to be drawn from those observations?

A. Each observation is given the value which is represented by both its co-ordinates; does not depend upon the value of one. I think that answers your question.

Q. But the weight of the conclusion is greatly strengthened by range of lake stage in the discharge observations, other things being equal?

A. The weight of any conclusion as to the variation of discharge, with change of stage, is increased as you increase the range of the observations; other things being equal.

Q. When you spoke of the adoption of the method by Government Engineers in your direct testimony, what did you have in mind specifically?

A. I had in mind having seen a reference to it in some one of the Government publications. At that moment I was not able to recall it. I have looked for it, not very exhaustively, since. I don't find it where I thought it was.

Q. Was it among the Lake Survey publications?

A. I surmised that it was and looked for it there and didn't find it. Whether it was or not, I am not prepared to say at this moment.

Q. Isn't it a fact that the use, the only use which was ever made of it by the Government Engineers, was in an unpublished report by Mr. Richmond?

A. I doubt if that is where I saw it, although I may have. I have not read that report in full, although I have looked through it.

Q. Do you recall now whether the method was made use of in any way, in that report?

A. I don't recall that it was.

Q. So it is your recollection that appeared, or there was a reference to it some place else?

A. My recollection was that I saw it in print. I may be in error about it because I have only a very dim recollection.

Q. Aside from that indefinite recollection, you have no specific knowledge that the Government Engineers have accepted this as a recognized and established method for reaching conclusions such as are under consideration in this case, on a series of observations?

A. I have no specific citations.

Q. Do you know whether it is made use of by scientists in general for handling observations of the same general kind; by physicists, astronomers and other scientists who have occasion to derive laws from series of observations?

A. I do not. It is of course only applicable to straight line observations. It is not applicable to those where a curve would be the *locus*.

Q. Now there has been another method to which you have referred; there has been reference made to it throughout this testimony, called the method of "least squares".

A. Yes.

Q. Isn't it a fact that is the method which is in general use among scientists in dealing with a series of observations of the kind we have under consideration?

A. It is a method which is extensively used by some scientists in dealing with observations. But early in my career I had that method characterized in a manner which I must say it—I have found to be quite accurately descriptive of its use, in many cases where it is attempted to use it. An old Professor of mine said that the method of least squares was a device of lazy engineers to make up in the office for deficiencies in the field. And my observation of those men who have in the main introduced it into ordinary calculations has been that the intricacy and complication of the method has led them to lose sight of the fundamental physical elements which are involved in the problems being investigated.

I am not applying this criticism to such experts as some of the witnesses in this case, nor to many eminent scientists who use the method properly, and whose use of it no one would venture to criticise. But it is a method in which the

manipulations tend to obscure and smooth out and eradicate the characteristics of the original observations.

Q. It is a method however which has been adopted to the extent that a number of very eminent mathematicians have written books about it, and have given credit to it, is it not?

A. Yes, it is a very useful method, and is probably at the present day the most accurate one that we have for deriving the locus or equation where the locus is a curve.

Q. Is it still applicable where the line is a straight line?

A. It is applicable, but it is no more accurate than the method I have used, and involves very much more labor.

Q. That is your opinion, it is no more accurate?

A. That is my opinion of the matter, certainly.

Q. It is a fact that many of the laws which have been derived by scientists from observations have been derived from the method of lease squares, is it not?

A. It is.

Q. Who are some of the mathematicians who have written books giving validity to that method?

A. I don't know that I recall at the present moment.

Q. Do you recall Merriman's Treatises?

A. I would hardly classify Mr. Merriman as a mathematician.

Q. Who was he?

A. He was at one time Professor of Civil Engineering at the Lehigh University. He was the editor of the American Civil Engineers' Pocketbook. He is an author of certain treatises on certain engineering subjects and is the author of a book on the method of least squares. I never heard him classed as a mathematician.

Q. Perhaps there is something in the use of the word "mathematician" that involves a distinction in your mind. You spoke of the American Civil Engineers' Pocketbook, Mansfield Merriam Editor in Chief. That is a standard authority among those who make engineering and scientific observations?

A. I hardly think that the book has been in use long enough to be called a standard.

Q. You contributed something to it, didn't you?

A. I did.

Q. Is it a book that is in general use?

A. Becoming so.

Q. What I am trying to get at is this, Mr. Williams: We have a situation where it is necessary to determine a relation growing out of a series of observations. Now if we

wanted to find out the method which was to be used in deriving that relation, not by working out a method ourselves but by going to the authorities for it, where would we go to find a recognized authoritative way of deriving that relation except we go to these books on least squares, which have been written by Mr. Merriman and other men who have dealt with that question.

A. To determine a straight line passing through a series of observations, I would go to the fundamental principles of mechanics.

Q. Would the other scientists go there too?

A. I suppose they would.

Q. Isn't it a fact that the least squares is based on that?

A. In part, and in part on the theorum of probabilities which is a mathematical proposition as distinguished from a mechanical.

Q. Through how many editions has Mr. Merriman's book gone?

A. I don't know.

Q. It has gone through several, hasn't it?

A. I presume so.

Q. What other authorities are there in which this method of least squares has been considered?

A. I think it is generally discussed on works of mathematical astronomy.

Q. Chauvenet?

A. I think Chauvenet discusses it.

Q. Comstock?

A. I don't recall but I assume so because it is a process that is used particularly by the astronomers where they have to deal with complicated curves.

Q. How about Wright's Adjustment of Observations?

A. I am not familiar with it, but I would expect it would be practically certain it would be found in that.

Q. You have made a study of it have you?

A. To a limited extent.

Q. You have not studied the books to which we have been referring here this morning?

A. No, not to any great extent.

Q. Is it your opinion that assuming the accuracy of the observations, the curve derived for the Niagara River by the use of the method of least squares is rendered inaccurate because that method has been used in deriving the curve?

A. Not at all.

Q. Or in deriving a straight line?

A. Not at all.

Q. Treating a straight line as expressive of the relation within the range of the observations which have been studied?

A. Certainly. I have no criticism of the method of least squares, as far as applied to accurate observations.

Q. So that it is your judgment that so far as the determination of the relation for the Niagara River is concerned, it does not make any particular practical difference whether the method of least squares is used or whether the gravity method is used?

A. No, as long as you are confining both to a straight line relation. If you introduced the curve relation, then the method of least squares gives results which do not compare with the other, and which of course would be more accurate.

Q. You referred in your direct examination to the method of using a string as a method which was sometimes used, and it was referred to in the Government's testimony in this case. What part of the Government's testimony did you have in mind when you referred to this string method?

A. To the cross-examination of the Government's principal witness, Mr. Shenehon, in which I believe he used the expression: Stretch your thread or draw your line.

Q. I would like to have you refer to the particular part of the testimony in which there is that reference to this method which you have discussed in your direct examination, namely the use of the string?

A. I find your reference to threading the observation. Now, whether you used the word "thread" or not, I won't be certain; I mean in your testimony.

So far as a cursory examination of the record at the present time goes, I do not find a reference to either a string or a thread in the language reported as that of the complainant's principal witness. I find on page 251 the statement:

"After the observations as thus grouped are platted, a straight line is drawn threading these observations, and this straight line is taken to indicate the relation between lake elevation and volume of outflow."

It is my recollection that either in the record or out of it the witness explained that these lines were located by stretching a thread across the observations, and adjusting it by the eye to the position which seemed to most nearly fit the group of observations.

Q. Now in your testimony in which you have presented an analysis, a criticism from your point of view, of the work done by the Government Engineers in drawing conclusions

from these measurements, you indicated, as I understood you, certain reasons why the work of the Government Engineers was not to be accepted with full faith and credit. And among the reasons assigned by you was the one that the method which had been used by the Government Engineers was a rough method and not really very accurate, and that therefore these results were to be discredited for that reason. Was that what you had in mind?

A. To the extent to which they varied from a correct location of the line in question.

Q. And another reason which you assigned for discrediting the conclusions of the Government Engineers was that the method of least squares was not to be taken as an accurate method of combining these observations?

A. I think not.

Q. You had no criticism to make based upon the use of the method of least squares?

A. Except the broad one that the method of least squares in no wise compensates for errors of one sign.

Q. But you do believe that both of these two things, namely the extreme refinement of the method of least squares and the rough and ready method of using a string are sources of inaccuracies?

A. Not at all.

Q. In the work of the Government Engineers?

A. Not at all as to the method of least squares; it is not a source of inaccuracy; but it does not eliminate the inaccuracies that it is assumed to do.

Q. Have you ever made use of this method of drawing a thread through observations, yourself, in work?

A. Oh, yes.

Mr. Adcock: When you say drawing a thread through, how do you mean it is drawn?

Mr. Wilkerson: Q. You understand what I mean. You plot your observations and you take—

A. You adjust the line through by the eye, in order to have a line that can be shifted readily.

Q. And you use one that most nearly represents the direction represented by the observations plotted?

A. Exactly.

Q. You have made use of that?

A. I have.

Q. And within what degree of precision have you found you could get results, by doing that?

A. It depends very largely upon the manner in which your observations are located.

Q. I asked you within what degree of precision you found you would get a line that way?

A. I don't know that I have in mind the specific range.

Q. Would the line be likely to be wrong to the extent of 50 per cent.?

A. Hardly.

Q. Or 100 per cent.?

A. Oh, no.

Q. Or 25 per cent.?

A. Not likely.

Q. Or assuming the accuracy of the observations, in dealing with observations such as those we are dealing with in this case for the Niagara River, would it possibly be 5 or 10 per cent.?

A. I hardly think you would be as far off as 10.

Q. Do you think you would be as far off as 5?

A. Just what is that question?

Q. (Question read as follows: "Or assuming the accuracy of the observations, in dealing with observations such as those we are dealing with in this case for the Niagara River, would it possibly be 5 or 10 per cent.?")

A. The question is as to the Niagara observations as they are, as I understand it. I think in that case it should have been right within 2 per cent.

Q. Taking into consideration the 219 observations utilized at the International Bridge Section, what accuracy do you give to the center of gravity or mean of all of these observations?

A. Well, the center of gravity is the mathematical point at which the resultant or counter resultant of that system of observations considered as forces would be applied to balance the observations.

Q. In your judgment as an engineer, what accuracy do you give to the mean volume of flow at the mean lake stage of these 219 observations?

A. Somewhere inside of 20 per cent.

Q. I show you a chart, which for the purpose of this cross-examination I ask to be marked Williams' Exhibit Cross-examination No. 3; the same being marked: "Discharge measurements of the Niagara River plotted from the records of the United States Lake Survey, International Bridge Section, Buffalo, New York. Measurements of 1898, 1899 and

1900 shown thus: By a circle. Measurements of 1907 and 1908 shown thus: By a plus mark. 101 measurements in 1898, 1899 and 1900; 118 measurements in 1907, 1908, making a total of 219 measurements."

I wish you would take this chart and assume that the observations have been accurately plotted; draw a thread which in your judgment correctly represents the law expressing the relation between the level of the lake and the volume of discharge.

(Chart shown to witness was marked Williams' Exhibit Cross-examination No. 3.)

A. That is between the level of the lake as indicated on this chart, and the volume of discharge as indicated on this chart?

Q. Exactly.

A. It is my opinion no line that can be drawn through those observations will represent that true law.

Q. Assuming they have been accurately plotted, draw a line which would represent the relation which is indicated by them.

Mr. Adcock: Don't you think that is too long to use a thread? Is the witness going to do this?

Mr. Wilkerson: He can have as many co-laborers or assistants as he thinks necessary.

(Witness draws line as requested.)

Mr. Wilkerson: Q. Will you please state what you have done, in response to my last question?

A. Will you take out the word "correctly" in your question? The point is this: I have drawn this as nearly as I can by the eye to what is a correct representation, but I do not want to say that it is a correct representation, because it is not. I object to the word "correctly."

Mr. Wilkerson: Well, take that out. We merely want your judgment in the drawing of the line.

A. If you will put it in this way: Will you draw a line which represents to the best of your ability the relation between the gauge height as indicated, or the lake elevation as indicated and the discharge as indicated?

Mr. Wilkerson: I will substitute that for my question.

The Witness: I have drawn such a line.

Q. Now, what does the line which you have drawn indicate?

A. This line passes through the alleged center of gravity of all the observations on this plate which I find to be indi-

cated by a star, and concerning which I am informed by the complainant's principal witness is the plotting of the center of gravity of these observations.

Q. You spoke of drawing that through a star which indicates the center of gravity. Would the line as you have drawn it have been substantially different, if that star had not been there?

A. Not substantially. I had as a matter of fact located the line within a very short distance of the star before I knew that it was the center of gravity.

Q. In accordance with the line which you have drawn, what volume of discharge is indicated by lake elevation 574?

A. 240,450 cubic feet per second.

Q. What is the volume of discharge indicated by lake elevation 570?

A. 154,000 cubic feet per second.

Mr. Austrian: Q. You are testifying from the plat in question?

A. I am testifying from what is indicated on that plat.

Mr. Wilkerson: Q. What is the increment which is indicated by the line, as you have drawn it?

A. 21,600 approximately.

Q. I am submitting to you, Mr. Williams, a computation of that increment by your three point method, and I will ask you to check the computation which is submitted to you and which for the purpose of the examination may be marked William's Memorandum Cross-Examination A, and after you have checked it to give us a statement of the increment for the Niagara as derived by the application of your Three Point Method. You find on the paper which has been submitted to you for examination a certain increment indicated. That would be 21,860?

A. 21,860.

Mr. Adcock: As I understand it, you have not checked those yet.

Mr. Wilkerson: Q. The memorandum submitted to you indicates an increment of 21,860 cubic feet.

A. I find on computation this increment to be 21,870.

Q. Assuming that the memorandum which has been submitted to you is accuraetly computed, I will ask you to state whether or not the increment derived by the Three Point Method is not substantially the increment which is indicated on Government's Exhibit plate number 3, showing the loss of

level in Lake Erie corresponding to loss of outflow in the Niagara River?

A. It is.

Q. And you understand that this is derived from the same 219 observations as was plotted on the chart which you have examined?

A. That is my understanding.

Q. Now that being true, isn't it a fact that this discussion of the method of stretching a string, and of the method of least squares, as compared with the three point method, is something which has no real substantial bearing upon the accuracy of the results which have been testified to by the Government Engineers in this case?

A. So far as the three point method and the method of least squares is concerned, my answer would be yes. I would say in a case of the importance of this, it does not seem to me that an engineer should rely upon the thread method for more than an approximate value.

Q. Would you regard it as an improper procedure for an engineer to take the thread method and see what it indicated; and use the result provided he found it tallied substantially with the result given by the application of the more intricate mathematical computation?

A. Oh, not at all.

Q. And for the purpose of simplifying evidence of this kind, wouldn't that be, in your opinion, the proper way of dealing with observations of this kind, to find the simplest method, one a layman could understand, and use that method and if he found on checking with the other computations that it was accurate, to make use of that method as explaining the way in which the law was derived?

A. I think as an illustrative method, its use was entirely correct.

Mr. Adcock: Q. But if it did not check what would you do about the line you had drawn, by drawing a string?

A. I would shift it until it did.

Mr. Wilkerson: Q. Assuming a possible inaccuracy of 2 per cent. in the computation of the increment due to the use of the string method or the thread method, what effect would that have upon the result as to the loss of lake level corresponding to the difference in the increment?

A. The error of increment—the proportionate error of increment would be the same as the proportional error in the lowering derived from it.

Q. And for a loss of level of four inches, say, the difference

would be 2 per cent. of four inches or .02 of 4 inches, .08 of an inch?

A. I think your mathematics is correct.

Q. Now, Mr. Williams, I wish you would draw on there with a dotted line or something, a line that would represent an increment of 34,000 cubic feet, the line passing through the center of gravity.

A. I have drawn such a line and marked it "Increment 34,000 c. f. s."

Q. In your opinion, does that line express the law of those observations, assuming the observations to have been made correctly and correctly plotted?

A. Not at all.

Q. With reference to the accuracy of the center of gravity, you stated in reply to a question that it was within 20 per cent. in your opinion. I wish you would state what in your judgment are the reasons for such inaccuracy, if there are any.

A. The difficulties of properly connecting the discharge at any given time with the elevation of the lake stage which produces that discharge, or the elevation of the lake surface which produces that discharge, and the difficulties of accurate measurement at the sections involved. Those are the primary elements; and the inadequacy of the number of points observed in the cross sections to determine the discharge accurately.

Q. Then there are two elements involved: One is the gage, and the other is the measurement of the volume.

A. One is the relation of the gauge to the discharge, and the other is the measurement of the discharge.

Q. Is the mean lake elevation indicated by these 219 observations practically the mean lake elevation at Cleveland?

A. For the same time?

Q. Yes.

A. I would expect it to be, approximately.

Q. Well, it would be so nearly it would not make any substantial difference in result.

A. I find on examination of the report of the International Waterways Commission on the Regulation of Lake Erie, tables X and XI, that the average elevation, the mean elevation of the Buffalo breakwater gage from 1860 to 1907, a very considerable portion of which has been derived by reference to the Cleveland gage, shows an elevation of the lake surface .07 of a foot higher than the elevation of the Cleveland gage as shown in table X.

I find that for the eight years from 1900 to 1907, inclusive, the average difference of elevation is .17 of a foot, and this in every case indicating the Buffalo water surface to be higher than the surface at Cleveland.

I find that this difference ranges from .05 of a foot in 1905 to .26 of a foot in 1906, those being the maximum limits of the range during these eight years. In view of that, I question somewhat whether one is warranted in saying that the indication of the Buffalo gage is to be taken as coincident with or corresponding to that of the Cleveland gage for the observations in question.

Q. What bearing do the years 1901 to 1906 have upon this inquiry which we now have under consideration?

A. The inquiry as I understand was whether or not the elevation as indicated at Buffalo for these 219 observations corresponded practically with the elevation at Cleveland at the same time; and I have examined the records of annual elevations of the two places for eight years, and I find this difference and as the result I draw the conclusion that they probably do not. I take these years as being the ones when there was a self-registering gage at Buffalo; and being the only ones when the self registering gage was there, during the entire year.

Q. Would it not be more pertinent to the inquiry to take the monthly mean of the gage for the months during which the observations in question were taken?

A. Yes, and more pertinent to take the daily observations at the two points during which they were taken.

Q. Is it not your judgment as an engineer, based upon an examination of these figures, that there is not a discrepancy of more than 1-10 of a foot between the Buffalo gage and the Cleveland gage, during the periods covered by these observations?

A. I have not examined the elevations of the Cleveland gage and the Buffalo gage critically for the periods covered by these observations. I would think that the probability was that the difference was greater than 1/10 of a foot.

Mr. Adcock: That is the mean?

A. The mean.

Mr. Wilkerson: Q. Do you think it would be substantially greater than 1/10 of a foot.

A. I am unable to say. I find differences here as the average of a year of .26 of a foot.

Q. Isn't it a fact if you take the Cleveland gage readings

during the period covered by these observations that they check very closely with the Buffalo gage observations?

A. I don't know.

Q. Isn't it your opinion that they do?

A. If you take the Cleveland gage readings during the times when the observations were actually taken, I think they do not.

Mr. Adcock: You are referring to the mean?

A. I am referring to the mean.

Mr. Wilkerson: Q. If those two gages were in substantial agreement during the time when the observations were taken, wouldn't that eliminate the element of fluctuation as governing the flow at the mean stage of the 219 observations?

A. It would not in my judgment.

Q. Why?

A. Because, as I have said before, we have no knowledge of what the stage of the lake is that corresponds to the discharge, except as it is secured by discharges carried over long periods of time, when this element of constantly changing lake can be eliminated by the balance of ups and downs.

If you will compare the continuous discharge of the Niagara River, measured for say a month, with the average elevation of the lake for that month, you should get an increment that would be somewhere near the approximately correct one, assuming the discharge observations to be correct.

Mr. Adcock: You mean at high and low.

A. Yes, if you compare the observations taken on the Niagara River for one or two or three months when the lake was at an average high stage, taking the mean of those discharges and the mean elevation of the lake for that period covered, and compare that with the mean discharges and mean elevations of the lake for a period of one, two or three months when the lake was at a low stage, and thereby derive an increment, you will be approximating to a correct increment, assuming that your discharge has been correctly measured. But so long as you are dealing with daily observations applied to daily gage readings, or to hourly observations applied to hourly gage readings, it is my opinion that you never can get a correct increment for Lake Erie, or any other of the Great Lakes.

Q. Throwing out of consideration the variation of discharge for the different lake stages, is it not your opinion that the Cleveland gage shows substantially the same elevation

during the times of the 219 observations under consideration as the Buffalo gage?

A. As I have made no specific comparison, I am not prepared to answer that question, and its answer would also depend upon the limitations that are put upon the word "substantially." If you mean within a foot my answer is yes. If you mean within 1/10 of a foot, my answer is no.

Q. Will you check up and make a computation as to the mean of the Cleveland gage, compared with the mean of the Buffalo gage during the times covered by the observations?

A. The following table represents the computation of the mean of the Cleveland gage compared with the mean of the Buffalo gage during the times covered by the observations.

Year.	Month.	Cleveland Elevation.	Buffalo Elevation.
1898	July	572.59	572.50
	September	572.01	572.08
	October	571.81	571.91
	November	571.69	572.01
	December	571.52	572.07
1899	February	571.46	571.59
	March	571.83	571.85
	May	572.44	572.32
	August	572.09	572.09
	September	571.85	571.90
	October	571.61	571.48
	November	571.62	571.55
	December	571.34	571.96
1900	June	572.47	572.41
	July	572.34	572.43
1907	October	572.69	572.79
	November	572.41	572.71
1908	June	......	......
	July	......	......
	August	......	......

Q. Now did you not state on yesterday that the relation between the volume of discharge and the level of Lake Erie at Buffalo was very definitely established by the computation of lake level from 107 observations of discharge, as stated by you in your evidence yesterday?

A. I think not. What I stated was that the relation between certain discharge observations and certain gage observations appeared to be very accurately established. I did not say that that was an establishment of the relation between

the level at Buffalo and the discharge at Niagara, as I do not believe that it was.

Mr. Adcock: These were the 107 selected observations you had?

Mr. Wilkerson: Yes.

Q. Now assuming that the relation between the volume of discharge and the level of Lake Erie at Buffalo was shown to be definitely established as was worked out on yesterday, and assuming that the stage at Cleveland is substantially the same as the stage at Buffalo during the times of the observations, wouldn't that indicate that you had a relation between the volume of discharge and the stage of the lake at Cleveland established?

A. I think not, for the reason that the simultaneous elevation of a lake with the discharge measurement is not the elevation that entirely controls the discharge.

Q. What do you mean by the term "entirely" as you have used it?

A. I mean when you consider simply the elevation of the lake at the moment the discharge measurement is taking place, you are ignoring the question of what the lake was doing during the antecedent minutes or hours, and thereby eliminating entirely the question of inertia, which is a very considerable one, as well as the question of the influence of elevations below the discharge station.

Q. When you said "not entirely," did you have anything in mind, any per cent.?

A. No.

Q. Is it about as substantial as the barometric column?

A. I think fully.

Q. And greater?

A. Very much. I think it is enough to change that increment from about 21,000 to about 34,000. And in bearing that out, I will show what just a little change will do.

During 1898, there were discharge measurements at Buffalo, from June 26th to August 6th. These were made, sometimes four a day, and ordinarily not more than one or two days was skipped.

Observations of discharge were made as follows: June 26th, one; June 27th, three; June 29th, two; June 30th, four; July 2d, four; July 6th, four; July 7th, two; July 8th, four; July 10th, four; July 16th, two; July 18th, two; July 20th, three; July 21st, three; July 22d, four; July 23d, four; July 24th, four; July 25th, three; July 27th, two; July 29th, two; July

30th, three; July 31st, four; August 1st, two; August 4th, four; August 5th, four; August 6th, four.

The mean discharge or the average——

Q. What year is this?

A. That is 1908. The average of all these discharge measurements is 223,774 cubic feet per second.

The average elevation of Lake Erie at the Buffalo gage for the same period, computed from the mean daily elevations is 573.26.

In 1898, between September 10th and October 21st, inclusive, there were observations made as follows:

September 10th, one; September 13th, two; September 15th, two; September 17th, two; September 20th, two; September 22d, two; September 24th, two; September 27th, two; September 29th, two; October 1st, two; October 4th, two; October 6th, two; October 8th, two; October 11th, two; October 13th, two; October 15th, two; October 17th, four; October 19th, two; October 21st, one.

The average discharge of all these observations is 190,097 cubic feet per second.

The average elevation computed from the average daily elevation of the Buffalo gage for the days included is 571.96.

The difference between the elevations in the first period, 573.26 and 571.96 is 1.30.

The difference between the discharge for the first period 223,774 and that for the second period 190,097 is 33,677.

33,677 the difference in discharge divided by 1.3, the difference in elevation, gives an increment of 25,900 cubic feet per second.

I submit, in my judgment, that is a more accurate increment than any that has been derived by the complainant in this case, and that it should be further corrected for the lack of more continuous observations, and a more extended period, to fully eliminate the effect of fluctuations on the Buffalo gage.

And it should be still further corrected by the necessary errors involved in the complainant's measurements of the Niagara Section.

Q. Do you think that 25,000 is more nearly accurate than 34,000?

A. I do not. I think that other is in the effects of these vibrations still that are not accounted for in this collection of data, and in the errors of discharge measurement.

Mr. Adcock: Do I understand if you had a great number of observations where the lake was at an even stage, low

stage, and a number of observations where it was at a higher stage, that you believe the increment would approach the 34,000 that you speak of?

A. It would, if the observations of discharge were accurate, but they are probably in error anywhere from 10 to 20 per cent., and therefore the increment is bound to be low.

Mr. Wilkerson: An error of 10 per cent. in the observations would make a difference, dealing with increments from 23,000 to 25,000, would make a difference of about 2,000 cubic feet a second, or a little more.

A. Depends altogether on how those errors were distributed.

Q. According to the law of probability, it would be so distributed it would tend somewhat to balance, wouldn't it?

A. That would depend upon whether the errors introduced greater effects at high discharges than they did at low, or *vice versa.*

Q. You have spoken of two kinds of fluctuations at the Buffalo gage, one of which you think affects the discharge and one of which does not. I wish you would explain just what you mean by that.

A. Well, the term fluctuation, as I have been using it recently, I have had mainly in mind what might be called vibrations or rapid changes of level. We also, unfortunately, used the term fluctuation to apply to the change of level in the mean from one year to another. That would be more properly——

Q. That is a variation of stage?

A. That is a variation of stage, and would more properly have been designated as the change of average annual elevation. I think in my testimony it was so designated; I endeavored to so designate it every time, in order that there might be no misunderstanding.

Q. So you have in your mind the distinction between the level of the lake at Buffalo at a particular time, and what might be called the stage of the lake?

A. I would understand by stage that average elevation which continues over an appreciable period of time, as say a month or a year.

We speak of monthly stages, and we mean the average elevation during that period.

Q. Now let us take this case: Take a difference of two feet in the gage readings at Amherstburg and Buffalo, the Buffalo gage reading 573. Now suppose at one time the Am-

herstburg gage read 571, and at another time the lake was level and the reading was 573, what in your opinion would be the effect of those two different conditions upon the volume of discharge of the Niagara, assuming that the 573 was continuous for several consecutive days?

A. You mean you are comparing two periods, one in which the lake is permanently tilted up to the extent of two feet in its length, so that the highest point, that at Buffalo, is at 573, with the case where the lake is level for several days, at the same elevation.

Q. Yes?

A. I would expect the larger discharge in the second case.

Q. You would expect to find a larger discharge during the period when the lake was level?

A. That is my opinion.

Q. To what extent? A. I am not able to say.

Q. Have you any definite opinion on that subject?

A. I have not except that it is one of the elements that accounts for the discrepancy between what the relations with the other lakes show to be the true increment of Lake Erie, and the apparent increment as derived from the observations that have been presented in this case.

Q. This example which I have given illustrates what you have meant by the two different kinds of elevations at Buffalo, the one where the lake is level and the other where it is tilted?

A. No, I don't think so; and I don't know as I used the term, two kinds of elevation. I think there is only one kind of elevation; that is when the water is up or down, or somewhere all the same level.

Q. This is so far as effect on the discharge is concerned?

A. That is only a part of the story, because in the actual procedure the lake did not generally remain tilted in this position for several days, but in fact was changed from hour to hour and day to day.

Q. Let us take over a period of one day then.

A. What is the question?

Q. The same question as I put to you before, taking it over the period of a single day?

A. I question, taking it over the period of a single day, whether in either case you would get the discharge that corresponded to the elevation of the lake, in either case.

Q. Why do you reach that conclusion?

A. Because it seems to me that it may take more than a

day for the full influence of change of lake elevation to make itself manifest in the discharge measurement.

Q. How would you establish that fact, by an investigation of the river slope, and other elements to be taken into consideration?

A. I don't think it can be established, because of the fact that the lake will not stand still long enough to let you establish it.

Q. Is it your opinion that the outflow of the Niagara River may be indicated by a gage at Chippewa?

A. I think so, subject to such variations in gage indication as would be due to changes in the flow of the Welland River.

Q. Do you know how large that flow is?

A. It is not large, but of course at times I would think it would cause an appreciable variation in the elevation of the gage. That is simply a judgment I have from looking at the map. An inspection of the locality might change my mind in regard to that entirely.

Q. Do you know whether there is an outflow of 100 cubic feet a second in the river, under ordinary conditions? It is a fact, isn't it, that the Welland Canal intercepts the river and takes off most of the flow?

A. I am not prepared to testify from personal knowledge in answer to either of those questions. My impression is that the flow of the Welland River on the average would not be more than 200 cubic feet per second; but the possibility occurs to me that in the event of a heavy local rain, or something of that sort, that the flow might be increased enough to affect the indication of the gage, and as I conceive, at Chippewa change of gage elevations will be comparatively small for changes of discharge. A small change in the elevation of the gage might have a significant influence upon the computed discharge of the river.

Q. That ratio is indicated by the relation of the gage at Chippewa to the one at Buffalo, to which reference was made on yesterday?

A. No, I don't think it is.

Q. Eliminating the Buffalo gage for the time being, may not the volume of flow be indicated by the gage at Chippewa?

A. I think so, if we had correct measurements to connect it with the discharge.

Q. By making the measurements at Chippewa and by measuring the volume of discharge at the International

Bridge, you can work out a relation between the stage of the lake at Chippewa and the volume of discharge, can you not?

A. Approximately.

Q. Within what limitations?

A. That would depend upon the influence of the volume between Chippewa and the gaging station that had to be filled with the flowing water before the full indication, the full effect of the increase or change of discharge would appear on the Chippewa gage.

Q. What is the source of inaccuracy?

A. The source of inaccuracy in connecting the discharge at Buffalo with the gage at Chippewa is involved in the volume of water that must be used in filling or emptying the prism of the river, to bring about the change in the Chippewa gage which corresponds to the condition at Buffalo.

In other words, if the discharge at Buffalo is that corresponding to an elevation one foot higher than corresponded to the elevation of the Chippewa gage at the time the discharge measurement began, then before the Chippewa gage would indicate the elevation corresponding to that discharge the water in the river must be raised by the addition to it of a volume whose base would be one foot at Buffalo, and whose area would be the area of the water surface between Buffalo and Chippewa, and whose lower edge would be the change of elevation of the Chippewa gage corresponding to the change of the foot at Buffalo.

This would take a certain amount of time and prevents the transmission of the measurement directly to Chippewa without an investigation and correction for this influence, the added or subtracted water depending on whether the water be rising or falling.

Q. For the river rising one foot in an hour, what would be the volume, the cubic feet per second, in the prism of water to which you have referred? I will ask you to compute that, and give the answer to the Commissioner, making an approximate computation?

A. It must be borne in mind that all the time that this water is rising, or being added, at Buffalo, it is also flowing away over the falls; that with each rise of the Chippewa gage, the flow over the falls is increased, so that it is not simply a measurement of the volume of that prism, but it is a computation of the volume of water that must be put into the river to fill this prism, which is more than the volume of the prism

actually is by the amount which flows out at Niagara over that which flowed out under the conditions with which you started.

Q. You will make the computation I have asked you?

A. I will endeavor to make it.

Q. How often do changes of a foot in the river come about, in your judgment?

A. Well, as I remember the testimony of yesterday, we found some thing like 18 of them in a matter of three months.

Q. The remaining days would be sufficient, wouldn't they?

A. Sufficient for what?

Q. To derive a relation between the Chippewa gage and the volume of discharge?

A. I think a relation could be derived.

Q. And if you did that the uncertainties as to Lake Erie's level would be eliminated, would they not, in the result?

A. They would be eliminated so far as the discharge of the Niagara River is concerned, assuming the discharge measurement itself to be accurate. But they would not be eliminated so far as connecting that discharge with the elevation of Lake Erie at the particular time of observation.

Q. In your judgment, Mr. Williams, may a relation be worked out connecting the varying stages of the lake at Cleveland with the elevation of the water, as indicated by the Chippewa gage?

A. I think so. You said "varying stages?"

Q. Yes.

A. Understanding stage to mean the elevation of the lake over a considerable period of time, as a month, I think that is correct.

Q. And if that were done, the effect would be to eliminate these inaccuracies which were due to the level of the lake at Buffalo, which you have specified in your discussion of this subject?

A. As a general proposition.

Q. That is to say, that a way of eliminating those inaccuracies would be to establish a relation between the gage at Cleveland and the gage at Chippewa, and having that relation in mind, to take that in connection with the volume of discharge as it was measured, and that would eliminate these inaccuracies due to the condition at the head of the Niagara River and Lake Erie?

A. To a very large extent, insofar as they affect the discharge measurements themselves.

Q. I will ask you to compute the elevation of the Niagara

River at Chippewa from the elevation of Lake Erie at Cleveland for the months of July and November inclusive, 1906. You may use for that purpose the elevations of Lake Erie appearing on page 93 of the report of the International Waterways Commission and you may make use of the law of gage relations established by the Lake Survey and described in the document entitled "Preservation of Niagara Falls," to which your attention has already been directed?

A. I will do so.

Q. Have you made the computation?

A. No, sir.

Q. Do you know whether it has been made or checked by Mr. Ayers, your assistant?

A. I know that Mr. Ayers has made some computation here with Mr. Shenehon. As to what that computation is, or what it represents, I am not informed at the present moment.

Q. This computation is a computation that as you understand has been made under an arrangement by which Mr. Shenehon and Mr. Ayers made some computation?

A. I assume so, but up to the present moment this computation has not been explained to me, nor did I know at the time it was made what it was, nor do I know what it is now, nor the result of it. And until I have an opportunity to examine it I am not prepared to testify about it. I presume in five minutes I will be ready to testify.

Mr. Wilkerson: We will adjourn for five minutes.

(After recess.)

The Witness: I now have made such computation.

Q. You are now ready to answer my previous question, are you, Mr. Williams?

A. The question I understood you to ask was if I would. I said I would. I now say I have made a computation.

Q. You have made the computation?

A. I have.

Q. What are the results of your computation?

A. The results of the computation indicate that for the period from July to November, 1906, and June to November, 1907, the monthly mean elevation of the Chippewa gage has been computed from the monthly mean elevation of the Cleveland gage by the application of the equation connecting the Buffalo gage with the Chippewa gage; and that the maximum variation of the computed elevation at Chippewa from the observed elevation was .18 of a foot, the computed elevation

being low; that the minimum was a check of zero in the second decimal place; and that the maximum excess of computed elevation at Chippewa over the observed was .07 of a foot.

Q. That is to say, Mr. Williams, you have been able in the manner indicated to take the water level at Cleveland, and from that to predict the water level at Chippewa, that is 180 miles across Lake Erie and 20 miles down the Niagara River, with a difference of 10 feet in slope, to within an inch?

A. In some cases the elevation being the monthly mean elevation, and not a daily elevation.

Q. The monthly mean elevation?

A. The monthly mean elevation. In one case, the error is something over two inches, but that is only for November, 1907. The others all falling within the inch.

Mr. Adcock: These were not daily or hourly elevations, but the monthly mean?

A. Monthly mean elevations.

Mr. Wilkerson: So that taking the elevation of Lake Erie as indicated by the monthly mean stage at Cleveland, and applying to that the relation between the discharge through the Niagara River, and lake elevation deduced by the Lake Survey officers, you find that you get a result as to the elevation at Chippewa which is precise, within the limits as stated by you?

A. Yes, sir.

Q. And the average of that is about a half an inch?

A. No, if you take them all in, it would be I think over one-half an inch; or, to state it another way perhaps would make it more clear: There are three months in which the computed elevation is within half an inch of the level of the actual. The others all exceed the half inch.

Mr. Adcock: How many months are involved?

A. Eleven months.

Mr. Wilkerson: What does that indicate to you, as an engineer, as to the correctness of the relation established between the stage of Lake Erie, as indicated by the gage at Cleveland, and the elevation of the Niagara River at Chippewa?

A. That, considering the monthly mean elevations at the two points, the relation is established with a reasonable degree of precision for gage comparisons.

Q. Well, is not the elevation of Lake Erie at Cleveland, as indicated by these monthly means, substantially the stage of Lake Erie?

A. That is what has been taken as representing the stage of Lake Erie.

Q. Have you computed the elevation at Chippewa from the mean elevation at Buffalo for similar months?

A. That computation has been made.

Q. And with what result?

A. It shows that for the period in 1906, July to November, inclusive, and the period in 1907, June to November, inclusive, the mean elevation of the Chippewa gage as being predicted from the mean elevation of the Buffalo gage, with a maximum variation of the computed from the observed of .03 of a foot, the observed elevation being greater than the computed; that both the computed and observed have agreed through the second decimal place on one occasion, and that on three occasions, the computed has exceeded the observed by .02 of a foot.

Q. That is to say from the mean elevations at Buffalo you have been able to predict the Chippewa gage within substantially a quarter of an inch?

A. That is correct.

Mr. Adcock: What is that monthly or mean?

A. That is the mean monthly.

Mr. Wilkerson: What does the accuracy of this prediction indicate to you, as an engineer, as to the reliability of the gage readings which are concerned here?

A. Why it indicates the probable accuracy of the monthly means of all the gages involved.

Q. Indicates a very high degree of accuracy, does it not?

A. Why it does not seem to me that is a high degree of accuracy for observations with a recording gage. You ought to get as close as that.

Q. What does it indicate as to the estimate of a relation between the monthly mean variations at Buffalo, and the monthly mean variations at Chippewa?

A. It indicates the establishment of a relation with a satisfactory degree of precision, so far as gage elevations are concerned.

Q. And I understand that the period covered is 11 months?

A. Yes.

Q. I show you two sheets, which for the purpose of your cross-examination I ask to have marked Williams Exhibit Cross-Examination Number 4, the same being the hourly water levels as recorded by self-registering gage at Chippewa, Ontario, during the month of November, 1906. And I am

using here photographic copies of those. These original documents have all been introduced in evidence in this case. One is for the Buffalo gage, November, 1906, and the other is the Chippewa gage November, 1906.

Mr. Adcock: Do I understand that the original of that has been in the record, or referred to in some way? I understand that is the first time that any gage readings of the Chippewa have ever come into the case, except so far as they have been referred to in the last day or two?

Mr. Wilkerson: However that may be, they are photographic copies of the hourly water levels, as recorded by the Government gages and are a part of the official records and reports of the Lake Survey office; all of which have been utilized in this case on both sides.

Mr. Adcock: Yes, there is no question about that.

(Document shown witness was here marked Williams Exhibit Cross-Examination Number 4; same consisting of three sheets.)

Mr. Wilkerson: Will you compute from the daily mean elevations at Buffalo the corresponding daily mean elevations at Chippewa and the Niagara River?

A. These computations have been made.

Q. And have been checked as correct, as you understand it?

A. As I understand it.

Q. In the same way as the other computations were made and checked?

A. I assume so.

Q. What range of elevation at Buffalo is covered by that sheet?

Mr. Austrian: As appears from that table.

Mr. Wilkerson: Yes.

A. I see that elevations 571.48 for a mean daily and 574.60 for a mean daily appear as the record of the Buffalo gage.

Q. That is a range of more than three feet?

A. Yes, about 3.12 feet.

Q. What do you find as to the agreement between the computed elevation at Chippewa and the actual elevations?

A. They agree within about two inches.

Q. Do you mean that is the agreement of the——

A. That is the agreement of the means of individual days.

Q. That is the mean agreement?

A. No, not the mean. I say that they all agree within two inches.

Q. That is the outside figure?
A. That is the outside figure.
Q. What is the average of the agreement?
A. There is one case in which the agreement is exact; I find two cases in which the agreement is exact; another case in which it is within .01. From a casual inspection, I would say that the majority of these computations agree within less than one inch. I find that 14 of the observations, including three which agree exactly, agree within half an inch.
Q. Well, you have been able then to predict from the Buffalo gage, the gage at Chippewa within this limit that you have just stated?
A. Based on mean daily observations.
Q. Now I call your attention particularly to the observations for November 4th. The mean is 571.48, the predicted elevation at Chippewa was 562.05, was it not?
A. Yes.
Q. The actual elevation, mean elevation, 562.09?
A. Correct.
Q. The difference being .04 of a foot, or less than half an inch?
A. Slightly less than half an inch.
Q. Well, take the observations for the 27th of November. You find the mean elevation at Buffalo 573.31?
A. Yes.
Q. You find the predicted elevation at Chippewa 573.07?
A. 563.07.
Q. 563.07, which corresponds exactly?
A. Exactly.
Q. With the observed elevation at Chippewa, is that right?
A. That is correct.
Q. Now we have a range there of more than 2½ feet in the two days to which I have directed your attention, have we not?
A. I think so.
Q. 2.53, is it not?
A. You started out with the fourth, did you?
Q. 571.48, 573.31, difference 2.53?
A. I thought you were referring to this same pair that we had before.
Q. My question is how much of a range do we have?
A. You are referring to those two observations you just cited, or the entire range of the series.
Q. The two just cited.
A. I make that 1.83 feet.

Q. There is a range of 1.83?
A. That is it.
Q. Well, now, I direct your attention to the 22d.
A. Twenty-second of November?
Q. You find the mean elevation at Buffalo 574.60.
A. Correct.
Q. The predicted elevation at Chippewa 563.79; the observed elevation at Chippewa 563.92?
A. About an inch and three-quarters.
Q. What was the range between the 4th and the 22d?
A. 3.12 feet.
Q. 3.12?
A. Yes.
Q. Are these daily mean elevations what you could call a stage of Lake Erie?
A. Not according to the definition that we have been applying the word stage to. I would call them elevations. Of course you could call them daily stages if you want to.
Q. They would be daily stages?
A. Daily stages.
Q. The average daily stage of the lake?
A. The average daily stage of the lake.
Q. At Buffalo?
A. At Buffalo.
Q. Having in mind the data to which your attention has been directed in connection with this cross-examination, what is your opinion as an engineer as to the correctness of the formula or law by which the mean elevations at Buffalo have been connected with the elevations at Chippewa?
A. I think it is about as close as could be derived.
Q. And would indicate, from an engineering standpoint, a high degree of precision, would it not?
A. The characteristic precision of the United States Lake Survey.
Q. Now, the monthly mean elevation of the lake at Buffalo was 572.319?
A. That appears to be stated on the second sheet of this exhibit.
Q. How much above the mean was the mean level on the 22d and the 27th, above the monthly mean?
A. On the 27th, it was roughly a foot; and on the 22d roughly 2.3 feet.
Q. Now is it your opinion that under those conditions Lake Erie was tilted up, as you have been using that term?

A. Well, I could not tell without reference to the Amherstburg gage. I suspect that it probably was during the higher period.

Q. How else could the elevation at Buffalo be accounted for, except that the lake was tilted up?

A. Being November, I think it would be rather difficult to account for it in any other way.

Q. Then it is your opinion that those mean observations for those two days indicate that at those times the lake was tilted up?

A. I think so.

Q. And this indicates that even with the lake in that condition, the slope relations are maintained between the Buffalo gage and the Chippewa gage?

A. Within the limits shown in this comparison.

Q. Which are very close?

A. Well, that depends again on your definition of "close."

Q. As closely as you have pointed out? On the 27th it corresponds exactly, doesn't it?

A. I haven't the exhibit here at this moment.

Q. The 27th is the day on which we found the computed elevation at Chippewa corresponded exactly with the observed elevation?

A. On the 27th they corresponded exactly, that is certainly a very close coincidence.

Q. Well, now, you could go from the Chippewa gage to the Buffalo gage in the same way, could you not, Mr. Williams?

A. In the inverse way.

Q. Yes. The Chippewa gage is in a secluded position, and what would be your opinion of the results which you would reach if you worked back from the Chippewa gage to the Buffalo gage?

A. You mean results as to what?

Q. As to getting an accurate expression of the elevation of the lake at the Buffalo gage, the stage of the lake at the Buffalo gage?

A. For these particular observations, I should expect, if you worked them backwards, you would get the same result as working them forward. I do not see anything in the process which would lead you to anything when you add a certain quantity and then subtract the same quantity from the result, I do not see why you would not arrive at your original quantity.

Q. And in the absence of the Buffalo gage, you would be

able to predict substantially what the level was at Buffalo, would you not?

A. Within three or four inches.

Q. And at the outside, and with the same degree of precision as indicated with respect to predicting the Chippewa gage from the Buffalo gage?

A. Well, I consider that a comparison of 30 days is hardly sufficient to warrant one in saying what you could do generally. In these particular cases, you would have done so and so.

Q. Have you made any examination of this subject for the purpose of determining whether or not the results which are reached with the observations of 1906 as a basis, would be substantially the result reached at other times?

A. I have not, but I have no reason to expect that there would be very marked deviations.

Q. Now, Mr. Williams, you have computed the elevation of Niagara at Chippewa from the monthly mean stages at Cleveland with a certain degree of accuracy, to which you have testified; and with a still higher degree of accuracy, you have computed the elevation at Chippewa from the monthly means at Buffalo; and you have also computed with a degree of precision, which you have stated, the daily elevation at Chippewa from the daily mean at Buffalo, even at times when Lake Erie was tilted up to the extent of a foot or more. What is your conclusion as an engineer, having that in mind as to the identity of effect in outflow conditions in the lake elevations at Buffalo, whether the lake is tilted up or not?

A. Having in mind the fact that the computed differences on the daily observations are something more than 100 per cent. greater than those on the average monthly, it appears to me that it does indicate an influence due to tilting of the lake.

Q. How large an influence, now that this additional data has been called to your attention, do you think there is?

A. That is very difficult to say, because there is an effect of tilting in both, and you haven't got it eliminated in either case, so that it is not possible to make a direct comparison. The one in which the effect of tilting seems to be the larger seems to increase the error of the computation, as I said, about 100 per cent.

Q. Does it apparently increase or diminish the discharge?

A. In the one particular case of the high elevation, it appears that the discharge is increased, due to the tilted position

of the lake; and in the case where the lake is 1.1 foot lower, the computed agrees with the observed.

Adjourned to Thursday, July 24, 10 o'clock a. m.

(In chronological order, here follows the testimony of Mr. Joseph Ripley on Thursday, July 24, and the morning session of Friday, July 25th.)

After Recess Friday, July 25, 3 p. m.

GARDNER S. WILLIAMS resumed the stand and testified further as follows:

Mr. Wilkerson: Q. I wish to call your attention to a paragraph from Appendix Number 7 to the Report of the Board of Engineers on Deep Waterways Part 1. Appendix Number 7 is signed by C. B. Stewart, Assistant Engineer; page 299, referring to the discharge measurements made in the Niagara River at Buffalo between the dates September, 1897, and September, 1898, at the discharge section on the line of the guard rail, on the north side of the International Bridge. The paragraph is as follows:

"Eddies are produced by the piers, to some extent, but they do not extend more than about 5 feet from the pier, and in most cases the current remains practically linear, with about the same amount of fluctuations as near the middle of the span. It is thought that little error has been introduced from this source."

I will ask you whether or not in reaching your conclusion as to the measurements in the Niagara River you had in mind that statement?

A. I did not have that particular statement in mind when I made that answer, but I had in mind statements made or appearing in a paper read by Mr. Clinton B. Stewart, before the Western Society of Civil Engineers on December 20, 1899, or some three months after the date of this Appendix, in which it is stated, first:

"For the location of the stations on the discharge section, the shorter spans 1, 2, 3, 7, 8 and 9 were divided into eight equal parts, and the longer spans, 4, 5 and 6, in 12 equal parts; thus making the distance between stations about 20 feet. These stations were marked on the guard rail, etc."

Then later he says, speaking of observations with the direction current meter:

"The direction was practically constant between the 2-8 and 6-8 stations of the short spans; and between the 2-12 and 10-12 stations of the long spans. Next to the piers, the direction was somewhat variable, and the meter would swing through an angle of 10 or 15 degrees. In such cases, the mean of several determinations was taken as the direction."

Now, the stations being 20 feet wide, I would interpret that as meaning that between the 2-8 station it was constant, but it was not constant between the 0-2, or for a distance of about 40 feet.

Mr. Wilkerson: May I see the pamphlet from which you have just quoted?

The Witness: (Handing document to counsel.)

Mr. Wilkerson: Q. I direct your attention to page 488 of the document from which you have just quoted, which is a written discussion by Mr. E. E. Haskell of the paper of Mr. Stewart, from which you have quoted, and ask you to read the paragraph which I have marked there into the record; and I will ask you whether you had that statement of Mr. Haskell's in mind when you criticised these Niagara measurements?

A. (Reading.) "In regard to the bridge section, it is a much better one for discharge work than many would suppose. As Mr. Stewart has shown in his paper, the current sets very squarely through the bridge in all spans. Aside from the small eddies along the sides of the piers, and those caused by the sunken caisson, there were few of any magnitude to be seen. The ease and rapidity and the small expense with which observations can be made from such a bridge are a large consideration. The meter can always be set at the same point for a station, and in general the time required for measuring a full discharge is very much less than in work from boats."

That is quoted from a discussion by Mr. E. E. Haskell.

Q. Did you have that in mind?

A. I did.

Q. Now I call your attention to the report of the Chief of Engineers United States Army for the year 1900, page 5332. I direct your attention to the following statement commencing on page 5332:

"The analysis of meter positions was first made by Mr. C. B. Stewart in discussing the Deep Waterway observations

on this river, and out of this germ has been developed our own tables for meter location and a static method of sounding."

A. I had and also the next paragraph of the reference.

Q. If you will go ahead and read, or I will read it:

(Reading.) "The wetted perimeter of the Bridge Section, as developed by the soundings, is so broken and irregular, and the water is so perturbed and deflected by the bridge piers, and by a caisson that escaped during construction, and lies across a portion of span 6, that the validity of results derived from such a section may be questioned.

A discussion of this point, however, points to an error to be expected from this source but little in excess of that of an open-river section.

Let it be assumed that the eddies and boilings close to the piers make correct estimates of the flow impossible in areas extending for certain distances from them, and that the caisson lying across a portion of span 6 adds another uncertain area. The resulting indetermination as affecting the total volume of flow may be closely estimated as follows:

Taking the doubtful regions as those portions of the cross sectional area extending 10 feet in spans 1, 2; 8, 9, and 20 feet from the piers in the remaining spans; adding 300 square feet for the caisson, they are as follows:

	Square feet
Span 1	90
" 2	110
" 3	500
" 4	680
" 5	960
" 6	940
" 7	440
" 8	340
" 9	200
Total	4260

This is about 10 per cent. of the total cross section. With a velocity taken as half that of the mean velocity of the river, the discharge in question is 5 per cent. of the total volume.

It is not probable that the errors in estimating the flow in these 19 doubtful places will have the same sign. In some the quantity will be taken too great, and in some too small, so that the summation will balance error against error and eliminate a part of them. It will therefore be entirely safe

to assign 10 per cent. as a maximum error in the sum of the partial discharges.

With this liberal allowance, the indetermination in the volume of flow in the full river from this cause is seen to be 10 per cent. of 5 per cent., which is but ½ of 1 per cent."

Did you have that in mind?

A. By whom is that report signed?

Q. By Francis C. Shenehon, assistant engineer, and Mr. E. E. Haskell, assistant engineer, signed on page 5361?

A. I had that in mind, and also what to me seems a much more correct description of the conditions, which is to be found at the top of page 5342 which has already been read by me into the record. And I want to say that at the time I read that in, there seemed to be an idea that I was attempting to criticise the language. I read it because to my mind it was a most exact description of the conditions which existed between the bridge piers of the Niagara River; not with the idea of criticising the rhetoric or description but, as I say, now, as a most exact description of the conditions that existed in the Niagara gaging station, and as they were believed to exist by Mr. Shenehon, at the time he wrote this report.

Mr. Adcock: What is the quotation you refer to? Just read it.

Mr. Wilkerson: Q. What you read as justification for your comment on the measurements in the Niagara River was the general statement, whereas in both the writings of Mr. Shenehon and Mr. Haskell, and in those of Mr. Stewart, we do have a specific statement of the precise conditions, and of the error which it was deemed might possibly result from the difficulties.

Now, isn't it your view, if you were going to get a correct expression of an effect, you would go to that portion of the report which gives the data.

Mr. Adcock: What is the quotation referred to, Mr. Williams?

A. (Reading.) "In such a section as that of the International Bridge, the proper derivation of the velocity coefficient is the most difficult part of the river gaging. To obtain it, the writhing mass of water streaming through the bridge openings and eddying about the piers, spurting and lagging in minor pulsations, speeding faster as the lake rises, and flowing leisurely in its low stages must be congealed to a solid by some instantaneous method of survey, and its dimensions taken."

Now that is also signed by Francis C. Shenehon, assistant engineer, and Mr. E. E. Haskell, assistant engineer, and occurs somewhat later than this exact computation of the effect of these disturbances; and I would assume that the man, as he went on with his work, became more qualified to pass judgment on what he has done; and these concluding statements, these later statements were entitled to as great weight as his earlier ones.

Furthermore, from my personal investigation of the Niagara section, of the conditions of the river as I have passed over the bridge in the cars in the day time, and have seen the eddies come up to the surface, not only at the bridge piers, but elsewhere, I am convinced that the description on page 5342 is a correct description and that the estimates made on page 5332 are not sufficient to account for the errors introduced into the gagings by these oblique and turbulent currents.

Q. I direct your attention now to page 5361 of the report, which appears to be later than page 5342 of the report, and call your attention there to the paragraph where it says:

"It is exceedingly satisfactory to be able to report so close a check in the results of the measurements of the two sections."

A. Just where is that?

Q. Page 5361.

A. Yes, I see it now; I have got it.

Q. (Reading.) "The sections are very different, and received different methods of treatment. The Bridge Section index velocities depend on the B meter under the Detroit rating of this instrument by an excellent observer.

The open section velocities depend on the A meter, on the Buffalo base, by different methods and by different observers. The Bridge measurements were in 1898. Those of the Open Section, in 1899 and 1900. The former was from a fixed structure, the latter from a survey boat, whose influence on the current lines might be a factor in the result. The coefficient work has some elements common to both, especially the rating of the traveling meter. Yet it will be seen by a reference to the tables 4 that the co-efficients would not be appreciably changed by using any other established rating for the traveling meter. The co-efficients in both sections have been established by overwhelming numbers of observations, by accurate methods, and were derived by different methods of reduction.

Having a splendid equipment, the entire work has been carried out with greatest attention to fundamental principles and to details, and with the infinite patience demanded in gaging the many moods of this great river."

Did you have that in mind?

Mr. Adcock: What is the report signed by?

Mr. Wilkerson: By Mr. Shenehon and Mr. Haskell.

A. I had that in mind, and also this at the top of page 5334:

"The B meter is credited with a somewhat greater range in its diurnal fluctuations"—I don't know what the diurnal fluctuations are, but evidently are something or other—"And has a remarkable record for the pertinacity with which it clings to a mean rating. The original calibration of this instrument was in September, 1898. In February, 1900, an elaborate rating gave a value to the mean wheel revolutions but one per cent. different from its original rating. In the interim, the meter had suffered the vicissitudes of gaging a wicked section; it had been fouled on a ragged bottom and caught in the sheet iron sheathing of a bridge pier; had bent the blades of its wheel, and had then retrued; it had lost its tail and had it replaced by a somewhat different one; its standard lead had been changed for one three times as heavy; its pivot had been dulled by passing upwards of 5,000 miles of current thread through the wheel."

In view of that, it does not seem to me that was a particularly delicate instrument, nor one which would respond readily to these changes of velocity to which it was subjected. That it was, in fact I would almost call it a crude instrument, and it does not seem to me that this extreme exactness that is claimed can be predicated upon the work of an instrument which would stand any such handling as that; nor do I think that shows particularly good handling.

Mr. Adcock: How about the use of an instrument that had been through all that trouble?

A. (No response.)

Mr. Wilkerson: Q. Let me read some more:

"The strength of the instrument may be judged by this test; its sensitiveness may be gathered from its rating observations. These are necessary in order to interpret the registered revolutions as the meter spins in the stream into length of water thread, and thus obtain the speed of the current in feet per second."

The point is that in these reports with reference to these

measurements, it has been stated with exactness the data as to the error which might result from the section being located where it was; and also it has been stated that that checked with another section, and is that not the thing that is to be taken into consideration rather than any general statements about the appearance of the river?

A. I think not. One does not—

Q. The appearance of the river next to the piers?

A. One does not need to be told that there are oblique currents, or are not, when we can see the visible evidence of them on the surface of the river. When an eddy reaches the surface, it is an indication of a disturbance further down, and those disturbances in the water decrease as they pass away from the point where they originate, so that if an eddy appears on the surface, you can be sure that there was a much larger one where it started from, near the bottom. As to this analysis as to the effects and so on, that is the opinion of the observer.

So far as the comparison of the two sections is concerned, the Open Section was not far enough away to be entirely free of the same influences that caused disturbance in the Bridge Section.

Further than that, it is checking the same tool against the same tool, which is no check at all. It is simply two measurements with the same thing.

You may take a yard stick that is an inch short and measure the width of this room, and go out in the hall and come back and measure it again and you will get the same width; but the width will not be right. That is the situation here. You take an instrument that you do not know whether it is right or wrong. You measure, and you get a certain result. You go somewhere else and measure with the same instrument and get a similar result, and call that a check.

Now, it is a check upon the performance, the manual performance of the operation and a check upon the mental operations used in its reduction; but it is not a check upon the instrument itself nor upon the accuracy of the result. On the direct line between the accuracy of the work and the accuracy of the result, this work was very accurate. The result I do not believe to be accurate.

And furthermore I will say that had these results been made with a Price meter, which we all recognize would not have agreed with this within probably 3 or 4 per cent., every check that has been applied in this case could have been

applied to those results, with equal facility and equal agreement. If it had been made with a meter which registered 20 per cent. over the Haskell, every check that has been applied in this case could have been applied then. As far as these checks are concerned, you are simply jumping over a fence and then crawling back under it, and that is all there is to it.

Q. Let us take the case of the St. Clair River where there are such differences in velocities as are found in the different cross sections which have been measured there. Does the fact that a comparison of those results shows accuracy of the measurement within comparitively small limits have any effect upon your mind in reaching a conclusion as to the credit which may be given to water measurements of this kind?

A. They have. But the same thing applies there; that it is the same instrument and the same operation checked against the same instrument and the same operation.

Q. But under widely different circumstances?

A. Not very widely different circumstances. Let us assume that you had a meter there that registered 20 per cent. more, which rotated sufficiently more easily to have registered 20 per cent. more in the same current; and that by some mistake or other the rating of an instrument like the one here had been applied to it, your discharge would have been 20 per cent. greater, and every comparison you make now could have been made then; every check applied that you made then you could make now, and similar results obtained, but it would not have been an indication that the measurement was correct there. But these checks you have applied indicate exceptional workmanship; that the work has been very carefully done, but there were conditions there beyond the control of the observer.

Q. How far out of the way do you think on the average, as a general rule, these current meter observations have been?

A. In the large rivers?

Q. In the large rivers?

A. I think about 10 per cent.

Q. You think there is a possibility of their being 10 per cent. out of the way or as a matter of fact they have been 10 per cent. out of the way?

A. I think as a matter of fact they have been. I think it is very doubtful if there has ever been one made that was within 5 per cent.

Q. Have you been influenced in reaching that conclusion by the tests which were made on the Detroit River, and which

have been put into the record in this case; that is rating the current meters in the current itself?

A. You mean by the coloring matter, by the use of coloring matter?

Q. Yes?

A. I have, but bearing in mind that in the measurement of the Niagara River, the cross section of which was, if I remember correctly, something over 40,000 square feet, that there were actually occupied positions in that river by the meter of—while I will not undertake to be definite, I will say less than a thousand square feet were actually covered by the position of the meter wheels, at any time during the observations.

The current meter is an inferential device. It is not an absolute device that measures the velocity at a certain point, and it may measure it more or less accurately, but if it does, if you have only occupied 1 foot out of every 40, you cannot say within 5 per cent., or even within 10 per cent., that the velocities of the other 39 feet are the same. There you have got the measurement of 1 foot, and 39 feet that you have not investigated.

Now I say, gentlemen, that the chances of your getting within 5 per cent., or even 10 per cent. under those circumstances is extreemly remote, and I base that opinion, not only upon all this information, but upon my experience in measuring the velocity of water by inferential measurements, where the area of the cross section was absolutely determined, and where the quantity of water measured was absolutely determined.

Q. Is it your opinion that the Haskell meter registers, as a general rule, too high or too low?

A. Well, as a general rule, taking it in smooth water and without disturbances, it depends on its rating. If it is properly rated, it registers very nearly what it is rated, but when you apply to still water ratings or those taken at the surface of a body of water the conditions that the meter meets submerged 40 feet below, in a turbulent current, I feel that there is no reasonable comparison, that there is no limit that we can set upon the variation which that meter may show from the rating which it showed at the surface.

Q. If comparison of these conditions of turbulence shows the meter sometimes registers too high, and sometimes registers too low, isn't it a fact that is well understood in combining observations of this kind that the error on the one side

at one time is compensated by an error on the other side at another time, and in the long run these errors cancel each other to a large extent?

A. I see no reason for believing those particular errors would cancel each other. All the information I have indicates to me the meter registers low in those disturbed currents.

Q. Let us assume that the meter registers low a certain uniform per cent. low, if you used that meter over a long period of time, when speaking of relative results, you would have the same element, that the meter registers too low through all of them, so that for purposes of comparison the error in your reading is not such a material matter?

A. For purposes of comparison of one section with another, that is of very little consequence, but that has nothing to do with the measurement.

Mr. Adcock: The measurement would be too low?

A. The measurement would be too low.

Mr. Wilkerson: Q. And the measurement at another time would be correspondingly too low?

A. Yes.

Q. So that the difference would be about the same as if the meter had registered right?

A. That depends altogether upon the percentage by which the meter registers low. The difference will be affected by the same error that there is in the original registration.

Q. That is to say if you were comparing observations where there was a difference of say 40,000 cubic feet a second, and your meter was 5 per cent. out of the way, it would affect that difference by 2,000 cubic feet?

A. Exactly.

Q. As to this other point which you make, that you have measured only a small part of your cross section, and that it is unfair to assume that from measurements on a small number of points in a cross section you can reach a conclusion as to the entire body of water that goes through, have you been influenced in reaching your opinion by the corroborative check of the different cross sections of the rivers which have been measured, as the St. Clair River? Wouldn't that indicate that it is a proper process of reasoning to assume that the average of the conditions at the points measured is substantially the average condition of the whole cross section. Wouldn't these corroborative checks tend to show that you might properly use that method of reasoning?

A. I think not, because you would find if you adopted some

one point in the cross section, and used a meter only at that point, that your gagings would coincide more closely than they do when you use several points. And if you were to use a thousand points in a gaging, and compare it with another gaging in which you used a thousand points, those two gagings would not correspond as closely on an average as they do, perhaps, when you use twenty or forty points.

Q. You do not attribute to any inaccuracy in the rating of the meter any such difference in results between the increments in the Niagara River which you reach, and that reached by the Lake Survey, do you?

A. I don't know where to place it. I feel very sure that it is there.

Q. Do you think there is any possibility that any appreciable part grows out of the inaccuracy in the meter measurement?

A. I think that an appreciable part of it has come out of inaccuracy due to applying a rating over a straight course to the indications of the meter in disturbed water.

Q. I direct your attention to page 74 of the "Preservation of Niagara Falls", the same being a Senate document heretofore referred to in the evidence in this case; chapter 15 the first paragraph of which is:

"The hydraulic work of the Lake Survey on the outflow of the Great Lakes depends fundamentally for its accuracy on the proposition that the Haskell Current Meter rated on a still water base gives the true velocity of flowing water. The work of the Lake Survey, up to the time of the experiments here briefly described, contains no demonstration of this vital point."

And then there are tables given of tests of the accuracy of the Haskell Current Meter in the Detroit River, table LXVI, and with this conclusion:

"On June 1, 44 observations showed a mean velocity of 2.818 feet per second by the fluid and 2.806 by the meters; the meters giving a lower velocity by merely ½ of 1 per cent.

On June 2, 32 observations showed a mean velocity of 2.922 by fluid and by the meters 2.933; the meters giving a higher velocity by about ⅓ of 1 per cent. These small divergencies are the accepted errors of observation characteristic of hydraulic work. Individual observations show larger divergencies coming from fluctuating velocities. The tests demonstrate conclusively the correctness of the indications of the Haskell meters."

Mr. Adcock: The year was 1906 that the tests were made?
Mr. Wilkerson: Yes.

A. That evidence is in this case, testified to by Mr. Shenehon, and was given consideration, and I believe that for the conditions which are represented here those tests were about all that is claimed, but they were not tests made under conditions which the meter encountered in gaging the Niagara River, and therefore they do not apply.

Q. Were they made under the conditions under which the St. Clair River was measured?

A. In which the surface measurements of the St. Clair were made, they were reasonably comparable.

Q. How about the Detroit River?

A. The Detroit River would be the same; they apply to measurements near the surface of the stream.

Q. Do you attribute any part of the difference between the result which you have reached as to the increment for the St. Clair River and the result of the Lake Survey, to any inaccuracy in meter measurements; if so, what part of it?

A. Yes, I attribute some of it to inaccuracy in meter measurement.

Q. In your opinion, in what way would any inaccuracy of meter observations be reflected to a greater extent in the conclusions reached by the method of the Lake Survey, and those reached by your method?

A. I don't see that there would be any difference.

Q. Then why would meter observations have anything to do with the difference in the result which you have reached? I understand you have taken these observations and simply combined them by a different method; and have you eliminated the inaccuracy of the meter in the St. Clair, so far as any difference between your results and the Government is concerned?

A. For the value which I finally gave to the increment, I had in mind the possibility or probability, in fact I may say the certainty, of errors in the meter measurements.

Q. That is to say you took—

A. I allowed myself a variation of 10 per cent. in my mean.

Q. You made an increase of 10 per cent.?

A. I allowed myself a variation of 10 per cent. and gave the minimum figure.

Q. Why did you increase rather than decrease it?

A. Because all the information I had leads me to believe that these measurements are low.

Q. And you have no information on the subject except what appears from these reports and tests?

A. And from the experience of some 20 years on hydraulic work, in which I have been engaged in measuring water by various devices, current meters and others, comparing one device with another, studying the peculiarities of water under conditions where it could be studied to greater advantage than it has been able to be studied in these gagings.

Q. You never spent any time making studies at the International Bridge Section?

A. I never did stop to observe the condition of the water, or the current as it passes through.

Q. You say you did look at the water?

Mr. Austrian: He said he observed it.

Mr. Wilkerson: Where was that observation made?

A. All the way across the bridge.

Q. From the car window?

A. From the car window.

Q. That was the only observation?

A. I made it several times.

Q. But you never got off?

A. I never got off and examined the condition there at the bridge.

Mr. Austrian: That is you never walked over the water?

A. No.

Mr. Wilkerson: The point is you never stopped for purposes of making any kind of detailed investigation of the subject; it was a superficial examination made, in the time it takes the car to go over the bridge?

A. On one occasion the train was stopped on the bridge for some considerable time. The train was late and could not get its entrance, and I had an opportunity to make—of course it was only an observation of the surface, which I suppose may be called superficial, but I doubt if even the Government Engineers have seen anything below the surface.

Mr. Adcock: You know something about the bed of the river and so forth?

A. Based upon the evidence and information regarding it that is presented in these various reports and various papers that have been written on the subject.

Q. And the currents?

A. And the discussions which I have had with men who were members of Mr. Shenehon's party on these gagings. Three of them were students of mine, and I knew more or less of what was going on, naturally.

Mr. Wilkerson: You presented certain statements here regarding the dredging of material in the St. Clair River, and the effect of that dredging in your judgment upon the level of the lakes?

A. I did.

Q. And you spoke about computing the volume of the prism, as I recall it, which was equal to the quantity of work which had been done?

A. I think I gave an estimation of what the equivalent area would have been, if concentrated in a given length, in a given section.

Q. Now do you know what disposition was made of the material which was dredged from the different points in the St. Clair River?

A. Why it was dumped at various points, various places in the river, in the shallows generally, or in the lake.

Q. Do you know specifically where it was dumped?

Mr. Adcock: You mean each shovel full?

Mr. Wilkerson: No, in a general way what disposition was made of the material which was dredged out of the lake?

A. I know a very large amount of material was at one time dumped in the St. Clair River about over where the tunnel is, below Port Huron.

Q. That is to say there has been 584,982 cubic yards dumped there, has there not?

A. I don't remember the figures now. I presume I could look them up as I think I have them in detail.

Q. Is it your understanding that of the material which was removed from the St. Clair River practically all of it, that is to say, all of it except a little more than 7,000 cubic yards, which was dumped in Lake St. Clair, was deposited in the St. Clair River in the vicinity of the work?

A. No, I have no particular understanding about it. That material is reported in the report of the Chief of Engineers as having been removed. It was removed from the channel. It was put somewhere where it was not supposed to get back into the channel, and I assume the engineers were able to so locate it.

Q. Is it your understanding that there was removed from Black River at Port Huron more than 400,000 cubic yards, which was dumped in the St. Clair River in the vicinity of the International Tunnel?

A. I would have to look at my notes on the St. Clair River dredging before I answer that question; but it is my understanding the majority of the material removed from the

Black River in 1891, 1892 and 1893 was dumped in the St. Clair River over the tunnel at Port Huron.

Q. How about the material which was removed from Pine River?

A. I don't know where that was dumped.

Q. How about the material removed from Bell River, at Marine City, Michigan?

A. I don't know where that was dumped specifically, at the present time at least. I might have known once.

Q. And about the Detroit River, did you understand that a large amount, 800,000 cubic yards, which have been removed from the river Rouge at Detroit had been deposited in the Detroit River?

A. I assumed that it was. I didn't know.

Q. In the statement which you made with reference to the lowering effect of this dredging upon the level of the lakes, did you include anything except the material which had been dumped into the St. Clair River from the Black River?

A. I had in mind all those things.

Q. I do not recall that you stated anything about them?

A. No, nor did I—

Q. In the statement which you presented?

A. No, I did not state specifically that.

Mr. Adcock: You mean in his testimony?

Mr. Wilkerson: Yes.

The Witness: Here is the proposition: That is this material was moved from the channel. It was put somewhere else than in the channel. It was moved from the critical points in the channel to increase the discharging capacity of the channel at those points; and, its deposition in the shallows, or in very deep water, would have comparatively small influence upon the discharge of the river as compared with the effect of the excavation through the controlling point and through the shallow point.

Q. It unquestionably had some effect, though, didn't it?

A. Oh, some effect certainly.

Q. And is an element which ought properly to be taken into consideration in determining the effect of the dredging upon the level of the lakes?

A. And it was so considered.

Q. How did you consider it?

A. Why I considered it in this way: Here was a visible lowering of the lakes taking place suddenly; a change such as is not to be found elsewhere in the records of the lakes. It must have been brought about by some great cause. No

great effect is produced without some great cause. There could have been various causes for it. There might have been an extreme drouth for several years. There might have been something in the nature of excessive evaporation perhaps that would have affected it; or there might have been an increase in the discharging capacity of the river.

An examination of all the records that were available points to no extreme drouth, points to no remarkable change of evaporation; but we do find that large and important changes were made in the channels connecting the lakes at this time. The time of opening those improvements is coincident with the time when this rapidity of fall takes place; and unless some other reason can be found to explain that fall—and I might say that the principal witness of the Government was asked to explain it, and I think he succeeded in explaining about 0.4 of a foot of a fall out of something like 1 foot. His testimony can be referred to. I assumed that he was possessed of all the information that there was available in the Government archives bearing upon that point, and that after his testimony it was hardly necessary for me to search them further.

I had up to that time made a diligent search for a cause for that lowering, and the one which I found was the improvement of the channels. And I believe that that was the cause, and I believe that it will be impossible to find any other cause that will be adequate to explain even a small part of the lowering of Lakes Michigan-Huron which took place about 1889.

Q. Wasn't the testimony of the Government witness, Mr. Shenehon, to the effect that there was a general lowering of the lakes at that time, something that included Lake Erie as well as Lakes Huron and Michigan? We can get this straightened out, if you will refer us to just what you had in mind in connection with your reasoning on this subject.

A. I have in mind particularly the information set forth in tables XVIII and XIX of Williams' Exhibit 34. Table XVIII shows the average elevation of Lakes Huron, St. Clair and Erie, for the open season, being the months from April to November inclusive, from 1860 to 1912.

The first page of that table contains a summary showing the average elevation of these lakes for the period from 1860 to 1889. In that table, the average elevation for the open season of Lake Huron, for the period from 1860 to 1889 inclusive, is shown to be 582.10.

On the second page of that table are presented similarly the average elevations of the same lakes, and they are sum-

marized in periods, 1890 to 1907, 1890 to 1908, 1890 to 1910, 1890 to 1912, 1860 to 1908, 1860 to 1910, and 1860 to 1912; I will take as being the most complete information we have the average from 1890 to 1912; the mean elevation of Lake Huron for that period as being 580.64, showing that Lake Huron has changed in elevation 1.46 feet.

Referring to page 1 of table XVIII, the average elevation of Lake Erie for the period from 1860 to 1889 is 573.16; and on page 2 the average elevation of Lake Erie for the period from 1890 to 1912 inclusive is 572.32, which shows that Lake Erie in the same time was lowered .84 of a foot.

In other words, Lakes Michigan-Huron have lowered .62 feet more from their average position for the period from 1860 to 1889. Over the average from 1890 to 1912, this lowering is to be accounted for the same way. If it were produced by a drouth, by excessive evaporation, it should have affected all the lakes alike. It affected Lake Huron to a much greater extent than it affected either of the others. Therefore it was a cause which was effective and influential upon Lake Huron to an extent that it was not upon the others, and is to be looked for in the outlet to Lake Huron, or in a diversion of water somewhere from Lake Huron.

Now there is no diversion of water which came into play in 1890, and the evidence is that since the diversion of water at Chicago occurred, the average elevations of the lakes have been greater than they were during the ten years immediately before. So it follows that this change of Lake Huron has to be looked for in changes in the outlet of the lake. If you wish to make the comparison of the full year, the data is presented in table XIX, and perhaps it would be interesting.

The mean elevation of Lake Huron from 1860 to 1889 inclusive, for the entire year was 581.91. And its mean elevation, 1890 to 1912, was 580.43, showing a lowering of 1.48 feet.

The mean elevation of Erie from 1860 to 1889 inclusive, for the full year, was 572.92. And the mean elevation of Erie for the period from 1890 to 1912, inclusive, was 572.07, showing a lowering of Lake Erie of 0.85. Of that, Lake Huron had lowered .63 foot more than Lake Erie.

Mr. Adcock: You also compared the fluctuations during the former period with the fluctuations during the second period, as a further check, didn't you, Mr. Williams?

A. I did.

Mr. Adcock: That is the fluctuations of Huron.

Mr. Wilkerson: How much was the difference in elevation of Lake Huron for the period in question?

A. Between the two periods, you mean?

Q. Yes.

A. 1.48 feet based on the mean annual elevation.

Q. How much was the difference of Lake Erie?

A. .85.

Q. Assuming that the relation between the movement of Lakes Erie and Huron be, according to this rule of fluctuation which you derive here, 70, what would you expect the lowering of Lake Erie to be, based on the lowering of Lake Huron?

A. 1.036.

Q. What was the actual lowering?

A. .85.

Q. Your actual lowering you say was what?

A. .85.

Q. And the expected lowering?

A. The lowering obtained by multiplying the lowering of Lake Huron by .7 was 1.036.

Q. And the difference between them?

A. The difference is .186.

Q. The evidence of Mr. Shenehon on that subject was, as he advises me, .17, which is substantially the same thing?

A. I think so. I don't find it just at this moment, but my recollection is that Mr. Shenehon applied this method of computation to this data.

Q. Isn't it a proper method?

A. If you want to find out how much Lake Erie had lowered, if it had lowered 70 per cent. of Huron, yes.

Q. In deriving the increment of the Niagara River, did you not make use of that ratio of fluctuation, or a similar one?

A. I made use of the ratio .753, which represents the conditions of the period from 1860 to 1899. It did not seem to me proper to include in that ratio the conditions on the years after this change of condition.

Q. The difference due to the difference of periods would be very small, would it not?

A. Well, it is the difference between the 70 which he took and .753 which I took. That is all there is to it.

Q. For the purpose of this comparison we were making a little while ago, it would not make any substantial difference?

A. We are dealing with rather small quantities. We will

see what this .753 gives. If you apply the percentage .753, the lowering of Erie should have been 1.114, checking this actual lowering by .26 of a foot.

Q. Doesn't that in your judgment indicate the extent, that is .26 and .18, the lowering in Lakes Michigan-Huron caused by any change in the outflow conditions of the St. Clair and Detroit Rivers?

A. No.

Adjourned to Saturday, July 26, at 9 o'clock a. m.

(In chronological order here follows the testimony of Mr. Frederic P. Stearns, on Saturday, July 26, and Monday, July 28, 1913.)

Monday, July 28, 1913.

GARDNER S. WILLIAMS resumed:

Mr. Wilkerson: What lowering in your judgment as an engineer is indicated by these figures?

A. Those figures indicate the difference between the actual lowering of Lake Erie, and that which would be expected for a lowering of Lake Huron corresponding to the figures given, assuming the ratios of change of elevation of the two lakes to be correct.

Q. Based upon these figures, in your judgment as an engineer, what lowering of Lakes Michigan-Huron is indicated?

A. The lowering of Michigan and Huron indicated, is, of course, the difference between the elevations for the means of the two periods, if that is what you have in mind. If, however, you wish me to say what lowering of Michigan-Huron would be expected from the change of position of Lake Erie, then another computation is necessary.

Q. Assuming the ratio of fluctuation of Lake Huron and Lake Erie as 1.00 to 0.70, and assuming the value of the center of gravity of the mean elevations of the lakes for the 54 years, 1860 to 1912 (open season), shown on bottom line of table XVIII, second page, Williams' Exhibit Number 34 to be Lake Huron 581.46 and Lake Erie 572.79, compute the elevation of Lake Huron for the open seasons of the period 1860 to 1889 inclusive, from Lake Erie's elevation?

A. The computed elevation of Huron for the first period, to correspond with the elevation of Erie for that period would be 581.99 approximately.

Q. How much higher was the observed elevation of Lake Huron for the same period?

A. .11 of a foot.

Q. Now make the same computation for the period 1890 to 1912 inclusive.

A. 580.79.

Q. What was the observed elevation of Lake Huron for this latter period?

A. 580.64.

Q. A difference of how much?

A. .15.

Q. That is, the lake is .15 lower than your computed elevation?

A. Yes.

Q. Now in your judgment as an engineer, what do these figures indicate as to the lowering of Lakes Michigan-Huron between these two periods?

Mr. Adcock: Based on those figures?

Mr. Wilkerson: Yes, as to the lowering caused by change of regimen or channels, in the St. Clair River?

A. To my mind, the sum of these two quantities which amounts to .26 of a foot shows the difference of the difference between the positions of Lake Huron for the two periods, and the difference between the positions which it would have occupied had the assumed ratio of its movement with reference to Lake Erie maintained, indicates a quantity less than the effect of the change in regimen of the St. Clair River.

Q. Why is that true, in your opinion?

A. First because the ratio of change between Lake Huron and Erie changed about 1890. Prior to that time, according to my own computations, that ratio was .753 and since that time it has been .855.

It does not seem to me therefore, that either of these ratios is necessarily properly applicable to the problem in determining what the position of Lakes Michigan-Huron would have been with reference to Lake Erie, when extended over this wide range; the average for the first period being one during which the relation was .753 while the average for the second period, being one during which the relation was .855.

Q. But taking into consideration the figures which you have derived, do you still adhere to your original conclusion that Lakes Michigan-Huron have been lowered by changes in the St. Clair and Detroit Rivers to an extent of about a foot?

A. I still think that it is entirely possible that the levels

of Lakes Michigan and Huron have been changed to this extent, by the works under consideration.

Q. In view of the figures that you derived this morning, do you think it is a reasonable conclusion, or do you think it represents the maximum possible?

A. Considering only the elements involved in the preceding question, I would not think that a lowering of one foot was to be attributed to those improvements.

Mr. Adcock: What other things do you consider?

A. The actual lowering which did occur at this time, and the fact that it occurred within practically two years; that it was a sudden and we might say very great change of condition of the lake surfaces, and must have been brought about by some very exceptional cause.

Q. Didn't you make some comparison of the fluctuations of the mean, lake mean annual fluctuations during the former period as compared with the latter period?

A. I did.

Mr. Wilkerson: On what figures as to water levels do you base your conclusion that Lakes Michigan-Huron have lowered out of proportion to their proper lowering to the water surface of Lake Erie?

A. Upon the fact that the ratio of variation of annual mean has changed for the two periods.

Q. Isn't your conclusion that the ratio has changed for the two periods contradicted by the evidence of the agreement of the water levels themselves throughout the whole range of years, as indicated by the six-year groups in table XVIII of the Exhibit referred to?

A. I think not.

Q. Will you compute from the elevation of Lake Erie for each of the several six-year periods the elevation of Lake Huron, using the ratio previously used, and the mean elevation as a center of gravity? Compute also for the five-year period 1908 to 1912 the same elevation, Michigan-Huron.

A. I will, the results are as follows:

Period	Erie Change	Computed Huron Change.	Observed Huron Change.	Period	Computed Huron Elevation	Observed Huron Elevation
I to II	—0.516 ft	—0.74 ft	—0.698 ft	I	....	582.305
II " III	—0.054 "	—0.08 "	+0.364 "	II	581.565	581.607
III " IV	+0.294 "	+0.42 "	+0.117 "	III	581.527	581.971
IV " V	+0.055 "	+0.08 "	+0.427 "	IV	582.391	582.088
V " VI	—0.907 "	—1.30 "	—1.795 "	V	582.168	582.515
VI " VII	—0.35 "	—0.50 "	—0.31 "	VI	581.215	580.72
VII " VIII	—0.61 "	+0.87 "	+0.55 "	VII	580.22	580.41
VIII " IX	—0.30 "	—0.43 "	—0.54 "	VIII	581.28	580.96
				IX	580.53	580.42

Q. What conclusions do you reach from these computations?

A. That there was a decided change of relation between the periods V and VI or about 1889.

Q. How close, and in detail, what are the computed elevations of the Lake Huron surface, as compared with the actual observed elevations as indicated in Table XVIII?

A. The elevations are shown in the computation submitted.

For Period II the computed was 0.04 ft. low.
Por Period III the computed was 0.44 ft. low.
For Period IV the computed was 0.30 ft. high.
For Period V the computed was 0.35 ft. low.
For Period VI the computed was 0.50 ft. high.
For Period VII the computed was 0.19 ft. low.
For Period VIII the computed was 0.32 ft. high.
For Period IX the computed was 0.11 ft. high.

Q. In your opinion what does this computation show as to the extent to which Lakes Michigan-Huron have been changed by the condition in the channel of the St. Clair and Detroit River?

A. Nothing definite, except a change of relation about the time the dredging would have been most effective.

Depositions in the above entitled cause taken pursuant to notice before the Commissioner at the rooms of the Sanitary District, Karpen Building, Chicago, beginning October 8, 1913, 10:45 a. m.

Appearances: Mr. James H. Wilkerson and Mr. Albert L. Hopkins, representing the Government; Mr. Edmund D. Adcock and Mr. Alfred S. Austrian, representing the Sanitary District.

GARDNER S. WILLIAMS resumed the stand for further cross-examination by Mr. Wilkerson and testified as follows:

Q. One of the subjects about which you were testifying in New York, Mr. Williams, was certain conclusions which you expressed with reference to the change of the regimen of the St. Clair River?

A. That is correct.

Q. And as preliminary to a question or two which I wish to ask you at this time, I wish you would summarize what your conclusion was as to the time when that change occurred?

A. It occurred about 1889. The effect seems to appear along about 1886 or 1887, begin to appear, but the most marked change was between 1889 and 1891; during the years 1889 and 1890.

Q. The change as you concluded it had taken place was rather pronounced during the period 1886 to 1889?

A. Well, more particularly between 1888 and 1891. It is rather pronounced, yes.

Q. Now what cause did you assign for that change of regimen?

A. A considerable portion of it, the deepening in the channels of the St. Clair and Detroit Rivers.

Q. And what was the duration, as nearly as you can give it in your opinion of the scour causing this change of regimen, at the time you have indicated?

A. I don't consider it was a scour at all. I do not understand that the scour played any very marked part in it. It was due to the excavations in the channels very largely.

Q. Due to the excavations in the channels?

A. Yes.

Q. During what period?

A. Well, those excavations began a number of years earlier

than that, but they did not strike the critical points until along towards the end of this period.

Q. And you take the fact that there have been certain excavations during that period, and from that you reach the conclusion that there had been a change in the regimen of the river which would correspond to the excavations which you understood had been made?

A. Not exactly. What I did say was, having discovered a very pronounced change in the relations of the lake elevations at that time, I naturally looked for a cause for it, and failing to find it in the variations of rainfall, changes of temperature, probable evaporations, effects and so on, I naturally looked elsewhere and discovered that at that time the controlling sections, or the controlling section in the Detroit River was cut away by the construction of the original Lime Kiln Channel, thereby permitting an increased flow in the Detroit River; and that during this whole period improvements had been made in the St. Clair, which would tend to produce similar effects.

Q. Now, there having been a change in the channel, as you say, by which more water went through the river—

A. Yes.

Q. —I am trying to get this in as simple language as I can —where did that water go, in your opinion?

A. It goes into Lake Erie.

Q. And what effect would that have upon Lake Erie?

A. It raised Lake Erie.

Q. Now I suppose it would be possible, would it not, to make a plat which would show the observed elevations of Lakes Michigan-Huron and Lake Erie, extending over a period?

A. Why, there is such a one in evidence in this case, what is known as a hydrograph.

Q. Then it would be possible to take an equation or formula which would express the relation between the elevation of Lakes Michigan-Huron and Lake Erie, and to compute the estimated elevation of Lakes Michigan and Huron from Lake Erie, and *vice versa;* and show that upon a plat, would it not?

A. It would be entirely possible to compute a relation for the period of time that you chose. How accurately that would fit the conditions would depend of course upon the variables in the equation.

Q. Suppose a plat of that kind were prepared, which showed the observed elevations of the lakes, Lakes Michi-

gan-Huron, Lake Erie and Lake Ontario, and upon the same plat was shown the computed elevations of the lakes determined from a certain formula; and it were found that the estimated elevations corresponded with substantial accuracy to the observed elevations, what would that indicate as to the correctness of the formula or equation which was used in that computation?

A. It would depend all together upon the premises upon which the formula was based, as to whether it was a correct formula or not.

Q. If you take a formula and apply it over a long period of years, and you found that by applying that formula your computed elevation tallied with substantial accuracy with the observed elevations, would not that indicate a correct equation had been used in making the computation?

A. It would indicate that the mathematical treatment coincided substantially, or to whatever degree the coincidence was, with that which occurred, but it would not prove necessarily that the equation was founded upon sound theoretical grounds.

Q. Why wouldn't it?

A. Well, simply because you can get a relation between two varying quantities which may express for different periods, or through different ranges a quite close coincidence between computed and observed results, but that equation may as a matter of fact have no relation whatever to the actual causes or conditions which produce those results. That is the relation may be what we call purely empirical; that is not based upon reason but based simply upon the fact that this thing happens to fit.

Q. It would show that there was coincidence between the observed elevations and the computed?

A. It would show whatever existed. Of course, it would show that so far as the result of the computation was concerned that it agreed more or less closely, or however closely it might, with the observed condition. It would not show that the basis upon which that equation was founded was necessarily correct.

Q. That is, you mean to say it would not demonstrate absolutely that was true; that is there might have been some cause present at one time which was not present at another. Is that what you had in mind?

A. It might—it would not prove that the equation was based upon the reasons or the causes of the conditions. It

would prove that a relation had been found which for a range appeared to produce quite similar results.

Q. It would show that the figure which was adopted as expressing the relation between the elevation of the two lakes was the correct figure would it not, for the years in question, without regard to why that was the correct figure?

A. I don't quite get that question.

(Question withdrawn.)

Q. You gave us a figure which you said expressed the relation between the elevation of Lakes Michigan-Huron and Lake Erie.

A. Yes.

Q. That is a change of so much in Lakes Michigan and Huron would be reflected, a certain percentage of it would be reflected in Lake Erie?

A. That is it, depending on the average.

Q. You had a period before this period of marked change?

A. Yes.

Q. To which you testified you gave the figure. What was the figure you finally reached?

A. I think that the change in Lake Erie appeared to be about 75.3 per cent. of the change in Lake Huron prior to 1889.

Q. That is, prior to 1889. Then you took the period from 1889 to 1890—

A. From 1890 on; the two years there do not fit in; that is when this change occurred, and it does not fit into either period.

Q. Those two years are 1888 and 1889?

A. 1889 and 1890.

Q. 1889 and 1890?

A. I believe so.

Q. And then after those two years, what was the figure?

A. The changes of Lake Erie are about 85.5 per cent. of those of Huron. I think I will refer to the table, to make sure of it.

Q. 85 per cent., was that the figure?

A. 85½ per cent.

Q. So that in your testimony on the subject of the change of regimen of the St. Clair River, the years 1889 and 1890 are the ones that you have pointed out as being the years during which the sharp change had taken place?

A. That is as I recollect it.

Q. What was your conclusion as to the amount of that change?

A. Anywhere from six-tenths to a foot.

Q. That is, six-tenths of a foot was the lowest figure?

A. I think so.

Q. What was the highest figure of the range?

A. I will have to look and see. I think about a foot.

Q. That is, you reached the conclusion that during the years 1889 and 1890, there had been a change in the regimen of the St. Clair River, which had resulted in a change in the elevation of Lakes Michigan-Huron from .6 of a foot to a foot?

A. I don't know that I want to conclude it in just exactly those words.

Q. State it in the way you would like to have it stated?

A. The conclusion was that between the six-year period from 1884 to 1889 and the six-year period from 1890 to 1895, there was a change in average elevation of Lake Huron of 1.82 feet, and between the same periods there was a change in elevation of Lake Erie of .92 feet, or about half as much.

Q. The inference which you intended to be drawn from that is that during those two years, 1889 and 1890, something happened in the St. Clair River?

A. Or the Detroit River.

Q. Something happened in either the St. Clair River or the Detroit River—

A. Or both.

Q. —or both, which resulted in a change?

A. Which had its effect at that time.

Q. Which had its effect at that time, which resulted in a change of from .6 of a foot to a foot?

A. To a foot, yes.

Q. How could that be expressed in volume of flow, during those two years?

A. That depends altogether upon what the increment of the river was before the change occurred. Or, going backwards, it depends on what it was at the time the change was completed.

Q. Take the different figures which have been discussed here as representing the outside statement for the increment of the river, and how much of that change in outflow would that change in elevation be equivalent to?

A. Well, the outflow of the river at the end of the second period could not have been very different from what it was at the beginning of the first period, speaking now in averages. I am not speaking of a single year. We must confine our-

selves to a sufficient period to take care of ordinary fluctuations.

Q. What I am trying to get at is this: It is your theory in this case that during those two years, 1889 and 1890, there was what has been characterized as a marked change in these two rivers?

A. Yes.

Q. Or in one of them; the result of which was that during those two years, necessarily more water flowed out of Lake Michigan and Lake Huron than had flowed out during the corresponding period before?

A. That is correct.

Q. I want to get from you an expression of about how much more water during those two years went through the rivers, in your judgment, as the result of that change than had been going through the rivers before, or than would have gone through the rivers had there been no such change in regimen as you have assumed?

A. I am not prepared to answer that question at the present time. I was under the impression that I had some figures here which might enable me to answer it.

Q. I do not care for an absolutely exact answer so far as decimal points, or even so far as cubic feet is concerned, but I want to get from you some expression of about how much water must have gone through those rivers during those two years, how much more than before; that is, how much water the rivers would have drawn out of Michigan and Huron than they would have drawn if the change had not taken place?

A. Well, I am not prepared to answer that question at the present moment. I will endeavor to answer it for you during the day or to-morrow. But at the present moment I haven't in mind the quantity, for this reason; that at the beginning of the period—that is, this did not come as a sudden increase all at once, a large quantity of water suddenly flowing through the river, and suddenly stopping, but it increased over a period of years preceding, came to the maximum at about the time the Lime Kiln Channel—the cut was completed through the Lime Kiln Channel—and then gradually decreased until Lake Huron fell to a position where the discharge of the St. Clair and Detroit Rivers came back to substantially what it was in the first place.

Q. You have not as the result of your studies of the situation there in mind now any figure which would express the quantity of water, the excess quantity of water so to speak,

which went through those rivers during the two years you have spoken of, the years of marked change, the years which are taken out of the list of years because they do not tally with the other years?

A. I have not, in terms of the water which actually passed out, no, because I have never computed that.

Q. I call your attention to page 1309 of this record testimony of Mr. Stearns where he says, speaking of these two periods: 'The average increment during this period would have been 27,100 cubic feet per second, and as the difference in the discharging capacity of the channel as above estimated was not less than 24,700 cubic feet per second, the lowering would have been not less than 24,700 divided by 27,100, equal to .91 of a foot, or substantially 11 inches." The figure to which I am calling your attention particularly is that 24,700 cubic feet per second as representing the increased discharging capacity of the channel. Does that represent your view on that subject?

A. Very nearly. But bear in mind that is the discharging capacity, not the measure of the water that actually went down there because it did not discharge that quantity except for a very brief time. The lake immediately began to fall and the quantity of water passing down was decreased.

Q. There would be a small decrease? There would still be an increase in the amount discharged?

A. No, the river came to equilibrium finally after a time.

Q. How long a time would that take?

A. Well, it began falling, or rather the highest elevation of Lake Huron was in 1886. It then fell quite continuously until 1892. It raised slightly for the next two years and fell again in 1895. It apparently reached its minimum about 1896. I should say that it took about ten years.

Q. But these two years 1889 and 1890 were years which you eliminated for the reason that the change was going on so rapidly?

A. Yes, between 1888 and 1891 the lake fell 1.24 feet.

Q. So that if the change was going on rapidly during the years 1889 and 1890, a very considerable portion of this increased capacity, 24,700 cubic feet per second, would be reflected in increased outflow during those two years, wouldn't it, the change going on rapidly?

A. I will answer that question this way, that a greater increased flow would be apparent during these two years than during any other part of the period considered.

Q. About how much would be reflected during those two years?

A. That is the part I am not prepared to answer at the present moment. Whether I can arrive at an estimate of that quantity, I am unprepared to say at the present moment. As to the increased discharging capacity of the river, I feel pretty well satisfied with that quantity of 24,000 cubic feet per second. That is about the figure that I had.

Q. And it is true that if there was a rapid change going on during the two years 1889 and 1890, that there would be a very considerable part of it reflected during those two years?

A. There might be more than half of it. I do not say that there would be.

Q. The case presented there is analagous to the case presented by the construction of a dam in a river, is it not, only it is the converse of the situation?

A. Yes, the converse.

Q. Take the case of the Gut Dam in the St. Lawrence River, the effect of that is to diminish the capacity of the channel so that there would be a smaller discharging capacity?

A. Yes.

Q. And that would be reflected necessarily in the elevation of the level of the lake above the obstruction which was placed in the channel?

A. Certainly.

Q. And that would be seen in this way: If you had a computation of what the level ought to be and then you compared it with the observed elevation, the observed elevation would be higher than the computed elevation owing to the construction of the dam, just as in the case of the deepening of the channel the observed elevation would be lower than the computed elevation?

A. Understanding the computed elevation to be based upon the conditions before the changes were made.

Q. Yes, certainly?

A. That is correct.

Q. Now, if an excessive or extraordinary rainfall occurred for any year, for instance, on Lake Erie or Lake Ontario, and not excessive rainfall on Lakes Michigan-Huron, what would be the effect of that upon the computed elevation with respect to the observed elevation?

A. It would raise Lake Erie and Ontario to a greater extent relatively than Lake Huron would be raised.

Q. So that if there had been a difference in the rainfall

on the two lakes and if there had been an excessive rainfall on the one lake, that would have to be taken into consideration in determining what the real effect was due to the change of the channel?

A. Understanding your term "excessive' 'to mean excessive as related to the ordinary conditions on that lake.

Q. Yes.

A. That is the rainfall on Lake Ontario may be materially greater than that on Lake Huron normally. It has got to be based upon the fact that the normal rainfall of the drainage area is considered.

Q. Now, let us take the effect of an ice blockade in the river: Suppose ice blocked the St. Clair River in a particular year, what effect would that have on the curves of computed elevation as compared with actual elevation?

A. It would raise the level of Lake Huron and depress the level of Lake Erie during th period of its existence, and for a limited but unknown period thereafter.

Q. When you say unknown, you mean what?

A. I mean that we cannot tell; we don't know how long the effect would last.

Q. It would be more than a few weeks, wouldn't it?

A. Why, it would be on the St. Clair. I am not so sure of what the condition might be on Erie.

Q. I show you a chart which we will introduce in this case later, but which I wish to use in connection with some questions which I am going to ask you. I ask to have it marked Complainant's Exhibit A. October 8, 1913. (So marked.) The same being a chart headed: "Mean elevations of Lake Michigan-Huron, Lake Erie, Lake Ontario," on which appear to be plotted, first, the observed elevations of these lakes respectively, as shown by horizontal full lines. There is plotted the computed elevation, shown by horizontal dotted lines. In the first horizontal column, the dotted lines show elevations computed from Lake Erie by the equation: "Michigan-Huron elv. equals 577.595 plus 1.4286 (Erie minus 570.).

In the second horizontal line, the dotted lines show the elevations computed from Michigan-Huron by equation: Erie el. equals 571.68 plus 0.70 (Michigan-Huron el. minus 580). The circles there show elevations computed from equation:—Erie el. equals 567.99 plus 0.74 (Ontario el. minus 240).

In the third horizontal column the dotted lines show elevations computed from Lake Erie by equation:—Ontario el. equals 242.71 plus 1.3[illegible] (Erie minus 570).

Now, on the right-hand side of the paper there is another

chart in which the same things have been plotted according to five-year means. The scale on which the chart has been prepared appears at the extreme right-hand side, as well as at the left. The scale in inches appears in the column so marked, near the right-hand side of the chart.

This is offered as Complainant's Exhibit for Identification at this time.

On this chart, where the observed elevation is below the computed elevation, the difference is indicated by a red rectangle and where the observed elevation is higher than the computed elevation, there is a corresponding indication by a blue rectangle.

Look at these formulas which appear on this chart, Mr. Williams. Is that a correct method of computing the elevation of the one lake from the other, with the exception of the particular decimal which is adopted as expressing the relation between the levels of the two lakes as you understand it, leaving out of consideration the correctness of the decimal .70, .74?

A. It is an approximate method of predicting the elevation of one lake with reference to the elevation of the other, its accuracy depending upon the accuracy of the variation involved.

Q. When I use the word decimal there, I mean that figure which expresses the ratio of fluctuation.

A. You meant in one case the mixed number 1.4286.

Q. 0.70, 0.74, etc.

A. We in mathematics usually call them "coefficients."

Q. We will call them coefficients.

A. That is the ordinary term for them.

Q. When you say it is an approximate method, what do mean?

A. Well, I mean that I think a more exact relation could be derived.

Q. How much more exact?

A. I don't know until I try it.

Q. You mean that the degree of accuracy with which the elevation is predicted depends upon the particular coefficient which is used?

A. Exactly.

Q. And that is to say whether this is accurate or not depends upon the accuracy of the figures 1.4286, 0.70, 0.74 and 1.35, on the chart?

A. Yes.

Q. If those were accurate then the method of predicting would be accurate?

A. I will say that the method is a proper one to use for such comparisons. I question the accuracy of the coefficient involved.

Q. In my questions I was eliminating that.

A. Oh, I beg your pardon.

Q. I am assuming that the coefficient is accurate, then the chart, assuming the mechanical work is done correctly, would represent correctly the situation which we have been discussing here.

A. The charts show for themselves what they do represent. Here is a computed elevation by a certain formula, and an actual elevation which is somewhat different. Now, that is all there is to it. If the relation was correctly expressed, the computed would coincide with the actual, but it is impossible with any such simple expression as that that is involved here to get a relation or to get an equation which would correctly express these changes; and all we can do is to approximate. Now, the accuracy of the comparisons depends upon the closeness of the approximation.

Q. Having in mind how this chart has been prepared, would the fact that there was either a close coincidence or a wide divergence between the observed elevations and the elevations which have been predicted from the formula throw any light upon the correctness of the coefficient which had been used in the formula?

A. I rather object to the term "correctness" because I do not think any coefficient in a formula of this type could be correct.

Q. Well, say approximate?

A. I was going to say applicability.

A. I will accept your word, the word applicability; would it throw any light upon the applicability of the coefficient used?

A. It certainly would.

Q. What light would it throw?

A. The more closely the computed results coincide with the actual, the more applicable the coefficient becomes or appears to the conditions involved.

Q. And if you take these five year mean periods on the right hand side, the more nearly the computed elevations coincide with the observed elevations, the more nearly accurate the coefficient which had been employed would be?

A. That is correct.
Q. So that we may understand this chart in the record, we find there that for the period 1860 to 1864 the computed elevation coincides how nearly with the observed elevation according to the chart?
A. Well, the scale is in shape here where we cannot read it very well.
Q. I am doing this so that we will get it in inches in the record.
A. I will say about an inch and a half.
Q. And for the period 1865 to 1869, how nearly?
A. Oh, probably half an inch.
Q. 1870 to 1874?
A. About two inches.
Q. 1875 to 1879?
A. About two inches and a quarter.
Q. 1880 to 1884?
A. About a quarter of an inch.
Q. 1885 to 1889?
A. About three and three-fourths inches.
Q. 1890 to 1894?
A. Two and three-fourths inches.
Q. 1895 to 1899?
A. About three-quarters of an inch.
Q. 1900 to 1904?
A. About half an inch.
Q. 1905 to 1909?
A. About an inch and a quarter.
Q. And 1910 to 1912, the three year mean from 1910 to 1912?
A. Well, about two and three-fourths inches.
Q. On this chart it appears, does it not, that during the period from 1860 to 1864 the observed elevation was lower than the computed elevation?
A. Yes.
Q. And that during 1865 to 1869 it was lower than the computed elevation?
A. Yes.
Q. From 1870 to 1874 it was higher?
A. Yes.
Q. From 1875 to 1879 it was higher?
A. Yes.
Q. From 1880 to 1884 slightly lower?
A. I would call that a substantial coincidence.

Q. From 1885 tc 1889 it was higher; from 1890 to 1894 it was lower; from 1895 to 1899 it was lower; from 1900 to 1904 it was lower; from 1905 to 1909 it was lower, and the three year mean from 1910 to 1912 it was lower?

A. Yes.

Q. By the amounts which you have already indicated?

A. Which have been approximately indicated.

Q. The range of the lake covered during these five year periods is from 579.0—

A. Say roughly from 580 to 582½, or if you want it exactly—

Q. It is nearly 583.

A. 582½; each one of those squares is five-tenths of a foot.

Q. From 580 to 582½. So that we may have it here in the record, because I am going to have some questions follow here, let us take the second one of those horizontal columns, the five year mean period for Lake Erie, and just run through that and state what appears as to the coincidence between the computed elevation and the observed elevation.

A. Well, the coincidences should be within about seven-tenths of what the others were.

Q. Let us see what the chart shows.

A. I guess it shows about that; if it does not the work is not right; but should be of the opposite sign; that is when you have a red in the upper portion, you should have a blue in the lower, and you do.

Q. Now let us take the Ontario chart. If these were plotted in this way, and you had in any year an extraordinary condition as for instance an ice condition in 1901, or the construction of the Gut Dam to which we have referred, you would expect to see that reflected would you not on this chart?

A. That is what you would naturally expect to find, yes.

Q. And you do find it reflected here, do you not?

A. I at the present moment have not the data to locate the ice conditions. I would expect they would be reflected here, and I assume they are.

Q. Look at the year 1901, the observed elevation of Lakes Michigan-Huron there is very much higher than the computed elevation, is it not?

A. Yes.

Q. And that is what you would expect to find?

A. Yes.

Q. You are familiar with these ice conditions in the year 1901?

A. Somewhat.

Q. We have been talking about those all through this case, and that is what you would expect to find if those were plotted in this way. And you are familiar with the construction of the Gut Dam. We have that fact brought out?

A. That brought us into 1903.

Q. It begins to show in 1904, and it shows a marked effect there; your observed elevation is greater than the computed elevation continuously, and that is very marked on the chart, is it not?

A. Yes.

Q. Are you familiar with the difference in flow out of Lake Ontario prior to the construction of the Gut Dam and after the construction of that dam?

A. Well, my recollection of the testimony was to the effect that the construction of the Gut Dam reduced the discharging capacity of the river about five per cent., and of course the lake has risen or has pretty nearly risen by this time, I assume, so that it would now be discharging its normal quantity of water.

Q. But as soon as the dam was completed, it is indicated on the chart here that the effect was immediately reflected?

A. Certainly.

Q. Or very soon thereafter?

A. Certainly.

Q. Now let us take the year 1890, down in the column there. Suppose that for that year the average mean rainfall for both Ontario and Erie was extraordinary and excessive as compared with Michigan and Huron, what would you expect to find on this chart?

A. I would expect to find that Ontario and Erie would be high.

Q. Also assume in answering the question that there was an excessive rainfall, 12.4 inches on Ontario and 6.2 on Erie, what would you expect to find that is over the mean?

A. I should expect to find a greater rise in Ontario than I would find in Erie.

Q. And the elevation of Michigan-Huron, computed from Erie, would be higher than the observed elevation?

A. Yes.

Q. For the purpose of the question, assume that during the year 1890 there was an excess on Michigan-Huron of 1.6; that is to say that the rainfall was practically normal, so that assuming that state of facts you would expect to account for

the fact that Erie and Ontario were higher for those years and Michigan and Huron lower, that would be attributed to a difference in rainfall?

A. Partially, but the fact that Erie was very much higher than Ontario although the increase of rainfall was materially less would indicate to my mind that there must have been some other contributing cause to the high elevation of Erie.

Q. You are speaking of now as between Erie and Ontario?

A. I am.

Q. That is that there would be some cause operative between Erie and Ontario which would show a higher effect on Erie than it does on Ontario. Do you know of any important cause during that year that would account for that?

A. Why the discharge of water from Lake Huron into Erie of course would be expected to raise Erie before it raised Ontario.

Q. Well, Ontario is a foot higher as compared with the year before, isn't it?

A. Yes, but it has not increased its elevation with respect to Erie.

Q. And Erie is only seven inches higher?

A. To the extent that the difference in rainfall would seem to call for, especially bearing in mind the different characteristics of the watershed, that heavy rainfalls on Lake Erie are not likely to find their way to the lake in as great proportions as they are on Lake Ontario.

Q. Isn't it a fact that for that year 1890 the rise on Ontario was greater than the rise on Erie, the observed elevation, the actual rise of Ontario—

A. You mean the difference between the elevation that year and the year preceding?

Q. Yes?

A. Yes.

Q. So that if the condition as to rainfall were an ordinary condition, the observed elevations for Ontario would be much lower than it is; that would be the effect, would it not?

A. I would expect so.

Q. Assuming that this table has been drawn accurately, and assuming the facts to be on the rainfall as I have indicated to you, isn't it a fact that the year 1890 was a year of such abnormal conditions so far as rainfall is concerned that there was a wide divergence between the observed elevation of the lakes and the predicted elevation applying the ordinary coefficient?

A. There evidently was a wide divergence. Whether that is to be accounted for in rainfall is to be determined by comparing with other years when there were similar discrepancies of rainfall or irregularities and ascertaining whether under those conditions similar changes of elevation can be produced.

Q. There can be no doubt in your opinion it is partially attributable to that?

A. It is partially.

Q. To a very considerable degree?

A. I am not so sure about the considerable degree at the present moment.

Q. It must be, must it not?

A. It depends quite materially on the time when this rainfall occurred, distribution through the year and some other conditions.

Recess to 2:45 p. m.

After Recess 2:45 p. m.

GARDNER S. WILLIAMS, resumed.

Mr. Wilkerson: Q. Looking at this chart in the column for the year 1890, we were speaking of the observed elevation of Lakes Erie and Ontario as compared with the computed elevation?

A. Yes.

Q. And it was stated that the excess rainfall on Ontario was greater than the excess rainfall on Erie. Now if as a matter of fact the excess rainfall on Erie and Ontario had been the same, other conditions being equal, the observed elevation of Ontario would have coincided with the computed elevation, would it not?

A. I don't think it would quite inasmuch as the normal rainfalls on the two drainage areas are not the same.

Q. (Question read.)

A. The answer I think is correct understanding excess rainfall to be measured in inches. If it was in percentage then the answer would be yes substantially.

Q. It has been measured in inches?

A. If you mean by that question to ask it as measured in inches, then my answer was correct. If you want to say that

the excess was in percentage, then the relation should take care of it and the computation would coincide with the answer, assuming no other conditions enter in.

Q. Will you turn to the figures you used showing rainfall, run-off, etc., on the three drainage basins for the year 1890.

A. 1890; as I make it, it is 40.23 inches. That figure has not been checked recently.

Q. That is Erie?

A. That is Erie. That is taken from the report for 1903—Wheeler's.

Q. What was Ontario?

A. Ontario at the same time 48.72, as I make it.

Q. And Huron-Michigan?

A. Huron-Michigan is 33.78.

Q. Now, isn't it a fact that the rainfall on Erie and Ontario for the year 1890 was the largest rainfall for those two basins of any recorded year from 1883 to 1905?

A. That is correct.

Q. And so far as Michigan-Huron is concerned, the rainfall for 1890 was not the largest but was exceeded by that of several years?

A. It appears to have been exceeded in three years, namely, 1883, 1884 and 1893. I will have to correct that; I have got to put in two more years, also 1885 and 1886.

Q. How much above the mean was the rainfall on Michigan-Huron for 1890?

A. It was about 1.5 inches.

Q. Now, I understood you to say that you did not think that this difference between the observed and computed elevations for 1890 as shown on this chart could be accounted for entirely on the basis of the excessive rainfall on Erie and on Ontario. What other element did you think entered in?

A. I think the deepening of the channels in the St. Clair and Detroit Rivers.

Q. I call your attention to the manner in which the effect of the construction of the Gut Dam is reflected on the elevation of Lake Ontario as shown by this chart; there being a change there of about 10,000 cubic feet, 10 to 12,000 cubic feet in the discharge of the St. Lawrence River. Would you not think if that had entered into the situation in 1890, so far as the St. Clair and Detroit Rivers were concerned, to any appreciable extent, that the change of 24,700 cubic feet would be reflected in the chart in the same way?

A. No, because the construction of the Gut Dam was accomplished in a very short space of time, something like three

months. The effect was practically instantaneous, you might say, as far as yearly averages were concerned, whereas the effect of the work on the St. Clair and Detroit Rivers extended over a period of some 10 or 15 years; and it culminated in its maximum effect at the time I pointed out. The effect was increasing previous to that time and gradually diminished thereafter.

Q. You said that there was such a marked change for the years 1889 and 1890 that they had to be rejected as not being explained on the ordinary basis?

A. Yes.

Q. Wouldn't the effect of a marked change in 1889 and 1890 be reflected in the same way as a marked change brought about by the Gut Dam was reflected?

A. I think it is so reflected. You see that Lake Michigan is markedly lower than it should be; Lake Erie is higher; Lake Ontario is higher. There is nothing to account for the extreme heights of either Erie or Ontario, nor the lowering of Michigan except the change in the channels in between there.

Q. How about this rainfall in 1890?

A. I call your attention to 1893 when the rainfall on Lake Erie—1892, I should say—when the rainfall on Lake Erie was only 1.2 inches less than it was in 1890, and you do not find that it caused any rise in the elevation of Lake Erie as compared with the year before when the rainfall was substantially five inches less.

It, therefore, does not seem to me that this difference of one inch of rainfall between 1892 and 1890 can account for the increase of elevation of Lake Erie, as contended by the complainant; but that the rise both of Erie and Ontario is very largely made up of water delivered to them through the St. Clair and Detroit Rivers, which temporaririly raised those lakes until the increased value of the increment caused a delivery which brought them back to their normal stage.

Q. Will you make the same explanation as to Lake Ontario for the years 1890 to 1892?

A. Well, the excess rainfall on the drainage area of Lake Ontario in 1892 was something like 4½ inches above normal and was about the same amount—4½ inches—higher than in 1891; and we find that Lake Ontario fell so that I again cannot conceive how if an increase of rainfall, as claimed, of some 13 inches, 12 or 13 inches above the average in 1890 produced a rise of Lake Ontario here of something like a foot

that an increase of rainfall of some 4½ inches in 1892 has been accompanied by a fall of the lake level of about 3 inches.

Q. Where there is an excessive rainfall, it is a fact, is it not, Mr. Williams, that you get a greater percentage of run-off than where the condition is normal; that is, where the ground is saturated there will be a greater run-off?

A. As I said, it depends somewhat on the distribution of that rainfall throughout the year. If it was distributed in small showers you would not get as much, perhaps, as you would some other year when the rainfall was less, but came in accumulated heavy doses.

Q. Well, then, of course, it would necessarily follow in view of that situation, that any discussion of lake levels based upon a consideration of rainfall has introduced into it so many elements that it is a very unsatisfactory method of reasoning, is it not?

A. Oh, no, if you record it over a long enough period so as to get at average conditions, it is correct enough for relative conditions; but when you have two years only two years apart, you must look for some other causes than your rainfall to account for such fluctuations as you have here.

Q. I direct your attention to another chart, which I ask to have marked Complainant's Exhibit B of this date for Identification. It is entitled "The Relative Fluctuations of Water Surface, Lake Huron and St. Clair, Means of Six Months Period June to November inclusive, years 1883 to 1906." The elevation of Lake Huron at Harbor Beach is plotted in the vertical; the elevation of Lake St. Clair at the Flats is plotted in the horizontal. Do you see from the plotting of those elevations any evidence of an unusual amount of water passing down the St. Clair River in the years 1889 and 1890?

(Chart referred to in the question was marked Complainant's Exhibit B October 8, 1913; marked for Identification.)

A. I do not see that this plotting would indicate whether there was or was not.

Q. Having in mind the year 1901 and the conditions which were prevalent during that year.

A. I know that the years 1889-1890 show the lakes to have been at a higher level than they have been at any time since if I read the charts right, except in 1894, 1895, in which case St. Clair was a trifle higher; not so high as 1890, however.

Q. It does appear, however, that for those years they followed the law of fluctuation as indicated by the line which is drawn there in accordance with that equation, does it not?

A. It seems to fit those particular years better than any of the rest, so that I imagine the line was drawn to cover those years.

Q. I call your attention to the statement on the chart: "U. S. Lake Survey Equation from all Data: Elevation of St. Clair equals 574.85 plus .66 (Harbor Beach minus 580)." Assuming the line is drawn according to that information, you would hardly think it is fair to say it was drawn with reference to those two years?

A. Yes, those two years are included. The conditions of those two years are included in the total. They happen to be about the middle of the line and as you take average conditions, the upper end of the line being high and the lower low, it naturally passes through this average condition which occurred at this time when the lake was falling from one stage to the next. The method of drawing a line would cause it to pass through those two years under the conditions that actually existed, and matched them probably more closely than any of the others in the series.

Q. Suppose, referring to the Niagara River now, Mr. Williams, that a set of observations had been made at a third section of the river, and that the volume of discharge as computed from those observations tallied within ½ per cent. or 1 per cent. of the discharge as computed from the observations at the other sections what would you say of the weight which was to be given to that fact in determining whether or not it was possible to measure the discharge through the Niagara River?

A. I would say in the first place that it would indicate the accuracy with which the manipulations were carried out. In the second place, that if it was made with the same instruments that were used in the other measurements, that it proved very little as to the actual absolute accuracy of the work.

For example, you may take the width of this room, which I would say is substantially uniform, and measure it with a yardstick from which one inch had been cut off, and you might measure it at four or three different places, or as many different places as you want to, and you would get substantially the same result. They would all check, but they would all be in errror by the amount represented by that one inch which would be off in the length of the yardstick. That is just the case you have in your measurement. You are using the same apparatus all the time; the same inherent errors are there, and therefore you would have no proof any more than the

proof of the accuracy of the manipulation. It is not proof of the accuracy of the result.

Q. What were the reasons which you assigned why the observations could not be made accurately on the Niagara River?

A. Well, among them were the disturbed conditions of the water in the sections that were selected.

Q. Well, now, suppose the section selected in this was in an undisturbed condition, would the inaccuracy which would deal with that cause be present there, also?

A. If this disturbance were not there, certainly the inaccuracies due to it would not be present.

Q. That was the chief reason that you assigned for the inaccuracy of measurement of the Niagara, was it not, the disturbed condition of the water?

A. Well, I think that was a very important one. No, I don't think that is the chief reason. I think the variation of elevation of Lake Erie is another one; that is the difficulty of connecting the discharge with the elevation of the lake. If, for example, continuous measurements of discharge had been taken over a considerable number of days; that is, a meter had been kept at some index point in the section continuously and the observations are there taken, and at the same time investigations made of the condition of the vertical curve at various elevations of the lake, we would then have been in position to have come very much closer to a discharge than we are now.

Q. Are you to be understood as saying in your opinion there is something either in the construction of the current meter or the manner in which it was used or the conditions which are generally present in every part of the Niagara River, which causes the results derived from those measurements as to outflow from the Niagara River to be uniformly smaller than it is in fact?

A. I would not say that would be the case at every point in the Niagara River. I think it is quite possible there may be places where current meter gagings would over-register.

Q. Where do you think that would be?

A. In the slower portions of the river.

Q. In about what part of the river would that be?

A. At the present moment I am not prepared to say exactly.

Q. So you think there might be portions where the manner in which the current meter is constructed, and the manner

in which it registers would cause it to register too small an outflow?

A. No; too large.

Q. Too large an outflow rather than too small an outflow?

A. As ordinarily manipulated, yes.

Q. Would you say that if observations were made by the current meter, which we understand were used for these observations in this case at the two points which I have indicated to you on the map, being marked on the map by a red line, how would you say the current meter would register there in that part of the river?

A. What is the area of those combined sections as compared with the area at the International Bridge?

Q. You say it would depend on that?

A. I ask what it is before I answer.

Mr. Shenehon: It is considerably bigger.

Mr. Wilkerson: Assuming that the combined area of the two cross sections to which your attention has been directed is larger, is considerably larger than the cross section at the International Bridge Section?

A. The section at Oakfield does not appear to be to me a particularly good one. The other one is somewhat better, but I think both of them are subject to disturbances on account of shallows up-stream.

Q. Well, now, assume that the section in the West Channel, which is called the Oakfield Channel—assume that these measurements are made in two sections, one in the West Channel, called Oakfield, and the one in the East Channel, called Wickwire, and that the channels are sufficiently smooth for some distance above and below the sections, and that there is no boiling nor eddying of the water past or near the section, and that the computed velocity was less than three feet per second, would you say that the conditions for gaging were good if that were true?

A. As usually understood, yes; but in the light of the information on the chart, I would question both those sections as being particularly good.

Q. What do you see on the chart that indicates to you that good conditions for gaging are not obtainable in those two cross sections?

A. Well, the bar at the Red Spar Buoy Number Six some distance up-stream, about half a mile I should say, from section Oakfield, the curvature of the channel at that point which must have induced more or less oblique currents would be the principal criticism of that. And at section Wickwire, we also have

a bar on which there apparently is a buoy located considerably nearer the section, which occupies something over half the width of the river. After water has passed over an obstruction of that kind in the bottom, there is always a considerable disturbance in the lower portions of the river, and those would not for that reason be ideal sections. I would think that they were better than the International Bridge Section, though.

Q. And would the disturbance be of the same kind that you have indicated in your testimony prevailed at the International Bridge Section?

A. Probably not exactly.

Q. How would they differ?

A. I do not think there would be so much eddying, but there would be, I think, more of the forward and back pulsation. That, however, is largely speculative because nobody has been down those places.

Q. What about this effect of Lake Erie that you testified concerning upon the sections down there?

A. Well, so far as the effect of the rise and fall of Lake Erie is concerned, in connecting the gaging there with the elevation which produces it, it would be fully as difficult there if not more so than it would be here (indicating on map); that is, it would be fully as difficult at the lower sections as it would be at the International Bridge.

Q. But if there were inaccuracies of measurement due to the disturbed condition of the water in all three of these places, would you expect the effect of the disturbed condition to be such that the results would be substantially the same in all three sections?

A. No, I would not. I would at the bridge and open section. I would expect the results to be somewhat different down there.

Q. How much different?

A. Well, I am not able to say.

Q. I hand you a report here which is to be marked Government's Exhibit C of this date for identification, and two charts which will be marked Governments Exhibits D and E of this date for identification, one being a preliminary report showing the measurement of the Niagara River, two channels, called Oakfield and Wickwire, the one being chart showing still water ratings number 1 and 2, 1913, Smelting Works base, August, 1913, and the other discharge plotted against the Buffalo gage, September, 1913.

Assume that as a result of the measurement of that section as shown there in that report the volume of discharge as

deduced was half a per cent. less than that at the International Bridge, while the discharge as deduced from the observations at the open section was 1¼ per cent. less than that at the International Bridge section, what weight would you say that had on the question of whether or not it was possible to measure this volume of discharge at the Niagara River with substantial accuracy?

A. It would depend altogether upon the accuracy of the measuring instrument, assuming that similar manipulations have been carried out in both cases.

Q. Wouldn't it show that the measuring instrument had a pretty high degree of accuracy for the reason if the measuring instrument was inaccurate, the results would vary more than 1¼ per cent., and half of a per cent.?

A. I think not, because the conditions that you are dealing with are in a measure of the same nature all the time. You have certain dynamic forces in the water that have to be taken care of. In a still water rating those don't exist, and they have an influence. As to how great an influence, we do not know. But we do know this, that in disturbed water the Haskell meter registers low. If it registered similarly in all three places, the indications would be that the conditions must have been similar and inasmuch as we know the conditions were disturbed at the bridge, the inference is pretty fair they were also disturbed at these other locations, and from the contour of the bottom it appears they would be very likely to be.

Q. Assume for the purpose of your comment, Mr. Williams, that it will appear in this case by the overwhelming evidence of competent witnesses that the water there was not disturbed as it was at the International Bridge Section, and that the statemen which is contained here in the report that there were good conditions for gaging is a true statement of the conditions of the river, now assume that, what weight would you gave to that in reaching a conclusion as to whether or not this meter does register accurately?

A. It would be entitle dto considerable weight.

Q. I show you another chart which I ask to have marked Government's Exhibit F of this date for Identification, the same being entitled: "Water Level and Discharge Curves, Hourly Plottings Lake Erie and Niagara River." The first horizontal curve has under it elevations of water surface of Lake Erie at Buffalo gage in feet above sea level. Below is the curve of computed discharge based upon the equation Q equals 15,330 plus 21,900 (H B minus 570.00). Q is the volume of flow of cubic seconds feet. H B is height of Lake

Erie at Buffalo gage. The dots show measured discharge volume. That is to say for a given elevation at a particular hour we have the estimated discharge, and we plotted on that the actual observed discharge according to the measurements. Then immediately below that is plotted elevations of water surfaces in Gorge Pool of the Niagara River at Suspension Bridge Gage.

There are four sheets of this and I ask to have the other three marked Government's Exhibits G, H and I, for Identification.

I show you another chart which is to be marked Government's Exhibits for Identifications J, K and L, October 13, 1913, the same being the water level and discharge curves, hourly plottings Lake Erie and Niagara River, these being the discharge observations of the open section only.

(Whereupon the various documents shown to the witness were marked respectively Government's Exhibits C, D, E, F, G, H, I, J, K, and L, October 8, 1913.)

Adjourned to October 9, 1913, 10:00 o'clock a. m.

October 9, 1913, 10:00 a. m.

It is stipulated between the parties hereto that Messrs. Williams and Shenehon shall indicate upon the chart Williams' Exhibit 12, entitled "Buffalo Harbor and Niagara River to the Falls, N. Y.," the location of Section Oakfield and the location of Section Wickwire, at which it is represented by the Government discharge measurements were made during the months of July and August, 1913; it being understood that the Government is to introduce further evidence as to such discharge measurements.

GARDNER S. WILLIAMS, resumed:

Mr. Wilkerson: Q. Now please refer again to Government's Exhibit B of date October 8, 1913, for Identification.

A. All right.

Q. That is a chart designed to show the relative fluctuations of the water surfaces of Lake Huron-Michigan, taking means of six month periods June to November inclusive during the years 1883 to 1906 inclusive. The line appears to be drawn from United States Lake Survey equation from all data, the equation being stated on the face of the chart. I will not read it into the record again. There is a reference given there to the report of the United States Lake Survey

with reference to the determination of these relative fluctuations.

Now do I understand you to say that it is your opinion that the method which the United States Lake Survey has used in deriving this law of fluctuation between the water surfaces of the two lakes in question is not accurate?

A. Why, the result speaks for itself. It depends altogether upon what you call accurate. If you wish to follow the fluctuation of those lake surfaces, it would be necessary to use a broken line, because the same law does not apply after 1890 that applies before, referring now to the levels of Lake Michigan-Huron and Lake Erie; and the same is true as to St. Clair. Of course you can get a straight line which will approximate these results over the whole period, but its coincidence with the points for the various years will not be so close as the broken line would be.

If it is desired to get a single line through there, I have no objection to this one particularly. I presume it is the best single line that can be drawn.

Q. I rather gathered from what you said yesterday that perhaps you had in mind the fact that the method that had been used in the derivation of the line should have been this three point method?

A. Oh, no, I am not objecting to that at all.

Q. It is your view as an engineer that the line drawn by the three point method would be substantially the same as the line drawn by the Lake Survey?

A. I would not expect it to be different.

Q. So that if it was desired to obtain a law which would express the relative fluctuations of those two lakes during the period in question, the line drawn,—that is the method pursued—is not subject to criticism so far as the process itself is concerned?

A. Well, understanding that it is desired to get a single line which will represent approximately the variations of these lakes with reference to each other, I have no objection to the method that has been used here, so far as I can interpret it or criticise it from this drawing. I have not checked the plottings, anything of that sort, but I assume that the work has been accurately done.

Q. But it does appear from that line as drawn that there is nothing to indicate any radical change in the quantity of water going through Lake St. Clair during the year 1900, is there?

A. I think there is.

Q. Just so far as the line itself is concerned. Let us not debate the propriety of the line, but take the line itself.

A. The line has no bearing upon that question at all. If for instance the points prior to 1889 when arranged had plotted so that a line at an angle of 45 degrees with the horizontal axis would fit them and the points below them were so plotted that a line drawn at an angle of 45 degrees would fit all of them, but in order to get from one to the other there would have to be a vertical drop, these lines would be parallel, and several inches apart.

A single straight line would not show that break. If you are plotting the observations prior to 1889 and the line that fits them, and those subsequent and the line that fits them, you will find that there is a change about 1889.

Q. If you draw a single line and all the observations fit that approximately, wouldn't that indicate to you that was a correct line for the whole period?

A. No, not if when you draw the separate lines, they fit better.

Q. Look at the years 1893 to 1906 as they appear with reference to the line in question, the one being before 1889 and the other after 1906, wouldn't the fact that those—

A. What was the year?

Q. 1893 and 1906.

A. They are both of them after 1889 if I understand.

Q. 1893 and 1906?

A. Both of them since 1889.

Q. 1893 was very close to this period?

A. Yes.

Q. During which you say the radical change was going on, and was a time when according to your view of the situation the change was in process, as I understand it?

A. Yes.

Q. Take 1889 and 1905?

A. All right, what of it?

Q. What do you say of it?

A. I don't say anything of it. I say if you draw a line that fits your observations prior to 1889, it will have a different slope from the line you have drawn on that. If you draw a line which fits the observation since 1889 it will have a different slope from the line you have drawn and these two lines will not be parallel, and they will have a considerable intercept between them about 1889; and that indicates the change of condition in 1889.

Q. Look at the line running through 1887 and 1906. Now, both are right on the line.

A. That is entirely possible. They happened to be about—at some point this line has got to intersect the other lines.

Q. Well, 1885, 1887, 1905, 1906, 1897 and 1896?

A. With the small variations that there are in Lake St. Clair due to this cause, the range of difference here is not sufficient to demonstrate any very great inconsistency, in having two points fit this line. Here are 1901 and 1892.

Q. 1901 was the year of admittedly extraordinary conditions, was it not, on account of the ice condition, so that you would expect to find that off the line?

A. All right. Here is 1895 and 1896, two adjacent years under approximately the same conditions so far as conditions in the channel are concerned, you find a wide variation there, and it is simply due to the varying conditions of two subsequent years. You have 1889 and 1890, about the same difference there.

I call your attention also to the fact that this chart only goes back to 1883; that is they have only taken about six years before the critical period and then they compare it with some sixteen years since. If they will extend this period back to the beginning of their records, they will find this line will look different.

Q. It appears that it is an equation derived from all the data. That is the apparent statement here of the United States Lake Survey. Do you undertake to say that there are any data of which you have knowledge that are not included?

A. I say there was data not in this chart.

Q. The point to which I am directing your attention is, it seemed to me to be obvious to a mere layman that if as against the line which is drawn you have put down your observations for the years 1885, 1887, 1889, 1905, 1906, 1897 and 1896, and the line went through all those observations including observations before and after, and that they coincided very closely with the line, it seemed to a mere layman to indicate that was the correct line; that there was not such a radical change in 1890 as you have indicated?

A. On the other hand, if we introduce a line which divides this up into two, and we show it more nearly fits the points in question, and shows the break in 1889, it would be obvious to a layman our work would be more likely to be correct than the work presented here.

Q. I direct your attention to the chart in this case which has been marked J. R. F. Exhibit number 1, and ask you

whether you had in mind the statement or rather the inference drawn from that chart, so far as this dredging in the St. Clair and Detroit Rivers was concerned, that practically all of it was after 1890 and the most of it was in 1894 and 1895 and 1896?

A. I had in mind that to be the fact, but the critical point at which the dredging took place, namely, at the Lime Kiln, was in 1888 and 1889, if my memory serves me correctly. There was a large amount of material dredged afterwards at other points, very much more than there was then, but it was right then they cut the crest off the weir which held up Lake St. Clair.

Q. So that the result of your study of the effect of these large amounts of dredging in 1894, 1895 and 1896 was that that was of minor importance as compared with the smaller amount of dredging done in 1888 and 1889?

A. As affecting the levels of the lakes, it was. As affecting their fluctuation, no.

Another thing I am a little bit in doubt about; that is I would not want to cover that phase of the question, because the enlargement of the channel that took place likely enough tended to equalize the change of elevation of the two lakes.

Q. So that it would not be right to draw any conclusion in this case based upon the fact that we have high chimney peaks here in 1895 and 1896, and which refers to the change in the cross section of the St. Clair River?

A. You must interpret those in connection with the physical conditions which were involved. Those were, deepening the channels through long reaches. Here your deepening was at the Lime Kiln. There was a barrier which Nature had put there, which separated Lake St. Clair from Lake Erie, and when that barrier was broken through, cut through, it was just the reverse of your construction of the Gut Dam. It was the thing which was the most influential in maintaining the level of Lake St. Clair.

Q. So that it is possible in your opinion for a very small thing, physically speaking as far as the amount of excavation is concerned, or the physical change is concerned, to produce a much greater effect than a very large piece of work?

A. Certainly it would be. For example, if you go to deepen a channel, if you are going to deepen it materially, you will not get the effect of your deepening until you have taken out a channel clear enough. When you start at the upper end and come along down half way, you have a given depth and the probability is you will not have increased its discharge very

much. It depends all together, all the time, upon the contour of your bottom. If you are taking out a series of shallows, that is one thing. If you are deepening a continuous reach where there is a large flow, that is another.

Q. If you used a chart on which the drainage canal was put down as being a thread, a microscopic thing almost, on a piece of paper, it is hardly a fair kind of chart from which to draw the conclusion as to the effect that may be produced upon navigation and the Great Lakes, is it?

A. I don't see why it is not, inasmuch as that chart indicates the relative areas and the approximate hydraulic conditions.

Q. Here we have Mr. Freeman putting down on his chart for the year 1890 a little line where you almost need a reading glass to see it, and yet the great effect is produced by that, and you find things looking like chimney stacks that produce no effect.

A. The fact remains it was the removal of the Lime Kiln that had the greatest effect upon the level of Lake St. Clair.

Q. What legitimate use do you think ought to be made so far as an argument as to the change of the cross section of the St. Clair River is concerned, ought to be made from this chart J. R. F. Exhibit 1, in the light of what you testified to yesterday and today with reference to the change in 1889 and 1890? What use as an engineer do you think ought to be made of that chart as indicating the change in the cross section of the St. Clair and Detroit Rivers?

A. I think that clearly indicates that there has been a very material change in the cross section of the St. Clair and Detroit Rivers.

Q. But one which did not produce nearly the change you claim is produced by that very small excavation in 1890?

A. Yes, I think that statement is correct. That is large quantities do not produce as great an effect as the excavation of a small quantity from critical points.

Q. Or anything like it?

A. I am not prepared to say anything like it. I would like to call your attention to Plate 10 of Williams' Exhibit 34, where is indicated these quantities that have been taken out. It will be seen at the right hand end of the plate what was done at the Lime Kiln. They took out those marked points which had been serving really as weirs. That is Plate 10, entitled "Excavated Material."

Q. My point is that in your opinion produced a much great-

er effect than the taking out of this much larger quantity of material at a later date?

A. I think it did. I won't say a much greater effect, but it did have a greater immediate effect. That was like taking a dam out of a river.

Q. Just refer to that Plate 10 again. The effect of shaving off these rocky peaks, so to speak, was to make possible through the whole river navigation to a greater depth?

A. That was the purpose of it.

Q. And the effect; that was its effect, was it not, to increase the navigable capacity of the entire channel?

A. No, because it reduced the navigable capacity of the channel in certain places as the result of the lowering of the waters immediately above.

Q. I am speaking so far as the size of the boats which would go through is concerned.

A. I am speaking of the size of the boats; the opening of the Lime Kiln caused strandings in the vicinity of Grosse Point by the lowering of the water there.

Q. It did increase the depth of the navigable channel at the critical points?

A. It increased the depth of the channel at the Lime Kiln, but when you said throughout the whole depth, the whole channel, that is not true.

Mr. Hopkins: Q. A deeper boat could go through that channel after the excavation, deeper than before, even though it did lower it perhaps at some other places?

A. That statement is correct, Mr. Hopkins. A boat passing from Lake Huron to Lake Erie could be loaded to a deeper draft after this improvement than before, but a boat passing from Lake Huron to Detroit could not.

Mr. Wilkerson: Q. Now, with reference to these new Niagara observations, assuming them to have been made as indicated yesterday, and to show what it is represented they show, would the fact that they tally so far as the discharge measurements are concerned pretty closely with the former observations which had been made, would be a fact to which weight should be given in determining whether the entire series of observations formed an accurate basis for measuring the discharge of the river, did I understand you correctly as to that?

A. The agreement in the quantity of discharge as stated in Complainant's Exhibit C for identification between measurements made on the Niagara River previously and those made or reported to be made more recently at sections further down

the river would indicate either that both series of measurements were entitled to a high degree of confidence, and to be accepted as accurate within the usual limits of accuracy of such work, or that both series were influenced by similar conditions, or by conditions producing similar results.

Q. When you spoke of the degree of accuracy with which observations of this kind are generally accepted, you agree that is a high degree of accuracy?

A. I agree it is a high degree of accuracy; that is that these particular measurements of their kind are of a very high degree of accuracy.

Q. And what you said about checking the sections of the Niagara against each other would apply to the checking of the sections of the St. Clair?

A. Certainly.

Q. And the St. Lawrence also?

A. Yes, it is a general statement; would apply to sections at different points.

Q. Independent of some element which might enter into this which would influence the result largely, or in the same direction, it would indicate that so far as the making of the observations themselves was concerned, they had been made with a very high degree of precision?

A. It would indicate the precision which we have credited to the work of the United States Lake Survey on the occasions we have had opportunity to do so.

Q. That is, it would indicate that the men who made the observations so far as recording what actually happened with the instruments concerned, that they had been very accurate in recording what was measured?

A. I am not prepared to say that until I see what they recorded.

Q. If you did not know that, the fact it checked so nearly with the other, that all three checked would indicate accuracy in the work itself?

A. One would expect that it would, yes, sir.

Q. Naturally. Now, then, you said that it would indicate that there was some influence which was operating uniformly and to about the same extent throughout all three of the series of observations.

A. Or that there was some influence in each one which produced a result similar in each one. It might not be the same influence.

Q. Which in your opinion would it indicate?

A. I have not seen the observations yet. I am not pre-

pared to pass any judgment critically upon these last observations. They may turn out to be the best that have ever been made and prove these others are the best that have been made previously, as contended for by the Government, but I am suspicious that they may not.

Q. When you said it would indicate a common influence operating through all the series of observations, what did you have in mind?

A. Why, any influence that might be common to them all, more particularly—that is, the first one you would naturally think of would be meter errors.

Q. Let us take meter errors; you had in mind that the meter might under-register, and that the under-registration might be uniform.

A. Or that it might be so nearly uniform that minor variations in other cases would cause the net result to be practically uniform.

Q. And the fact that they check in that way would indicate that the error of registration was the same in different velocities?

A. Not necessarily. If you are confining it to meter errors alone, that would be a fair inference.

Q. I am speaking of meter errors. I am trying to find out just what you had in mind as to a constant source of inaccuracy in all three sets of observations. Now, this meter which was used was what is called the screw meter; that is it is of that type?

A. It is usually spoken of as propeller meter, I think. I don't know as it is called screw meter.

Q. As distinguished from a cup meter?

A. Yes, usually refer to it as propeller meter type.

Q. Do you understand it to be generally accepted by engineers who have made a study of this subject that where a cup meter is running in perturbed water it will register a larger number of revolutions per second than the still water rating would indicate?

A. It is likely to.

Q. That is the generally accepted view among the engineers who have studied that?

A. I think so.

Q. So much so it is regarded as one of the fundamental principles applicable to this subject?

A. One reason for it is that the direction of the meter has very little if any influence upon the speed of the rotation of the wheel because it receives its impact tangentially

all the time; makes no difference what direction the current comes from; it has the same effect in the rotating of the wheel.

Q. I understand from your testimony you regard it as established that where a propeller meter is run in perturbed water it will register a smaller number of revolutions than still water?

A. That seems to be the result of experiment.

Q. Do you know whether or not engineers who have made a critical study of this subject have reached a conclusion as to the possible extent to which a cup meter may over-register?

A. The subject has been discussed, but I doubt if anybody has established the limits.

Q. Isn't there among engineers a generally understood notion as to the limit of the over-registration of the cup meter?

A. No, I think not, because I have in mind a case in my own experience where the over-registration was, if I remember correctly, somewhere around 30 per cent.

Q. From 25 to 30 per cent. is as high as anybody has ever claimed for that?

A. It is not the case of a claim this time. It is a case of actual fact.

Q. I intended to say it has been found?

A. Generally speaking, though, Mr. Wilkerson, I think you would not ordinarily expect to find any such variations.

Q. Isn't it a generally accepted fact that the propeller meter will under-register by not more than 3 or 4 per cent.?

A. I don't think so, because I have seen observations where they under-registered more than that.

Q. I am speaking now of the results based upon a series of observations. It might happen in one particular observation under extraordinary circumstances where you would get more than that, but if you took a result derived from a series of observations, isn't it generally understood that the under-registration will not be more than 3 or 4 per cent.?

A. I don't think so.

Q. Do you understand that it is regarded as an established engineering fact that a propeller meter if it is run in perturbed water will give uniform records in equal times, provided those times are sufficiently long?

A. I presume that it would, provided they were sufficiently long, but they might have to be pretty long.

Q. How long do you think they would have to be?

A. That depends altogether upon the conditions of the disturbance. You must give time for those conditions to repeat themselves in the two periods that are compared. They might repeat themselves in a few minutes or a few hours or a month or a year.

Q. If you assume that a uniform amount of water was flowing through the channel to be measured, the meter would give uniform records in equal times provided the times were long enough to get it—a series of observations adequate for the purpose?

A. With those restrictions, I would say yes.

Q. So we have there as a possible element which you think should be taken into consideration the under-rating of the meter?

A. I think that is one possible element, yes.

Q. Now, what other element did you have in mind that might be a constant element?

A. You don't mean under-rating. I mean an under-reading.

Q. Under-registration?

A. Under-registration.

Q. I mean under-registration.

A. Yes, I answered your question as I thought you meant it and then I observed that what you said was the reverse of what you meant.

Q. What other element did you have in mind?

A. Where have we gotten to?

Mr. Adcock: Is this in determining the volume of discharge or computing the increment?

Mr. Wilkerson: First in computing the volume of discharge, what other element exécept the under-registration of the meter did you have in mind?

A. The fact that the section is not properly covered and that large portions of it are not measured or investigated at all.

Q. That would be something peculiar to the section itself. Now I am speaking of these general influences applicable to all three sections.

A. I think that is applicable to all three sections, because as a matter of fact you only occupy about 5 per cent. of the area of your cross section. In the other 95 per cent. there are great possibilities of things taking place that you get no indication of.

Q. Would the error growing out of the selection of the cross-section be uniformly in the same direction? Wouldn't

it very likely operate one way in one section and another way in a different section at a different time?

A. I conceive it might operate either way. It might happen to operate the same way in all three sections or might operate different ways.

Q. So isn't it a fact the only thing which you had in mind as an element of error which might operate to cause these observations to be influenced uniformly in the same direction is the element of the under-registration of the current meter?

A. There is also the element of inaccuracy of measuring the cross section. That would be another element that might very possibly be practically uniform.

Q. You mean the soundings?

A. Yes.

Q. How great do you think that would be as a percentage?

A. I am not prepared to say, because I have not given that very careful investigation. I should think there might be an error of 3 or 4 per cent.

Q. Assume a depth of 20 feet for the water, what would be the average?

A. I said 4 per cent.

Q. Four per cent. of 20 feet would be .8 of a foot. So that there would hardly be a constant error of 8 or 9 inches in the soundings, would there, Mr. Williams, sounding it in duplicate and every ten feet across the river?

A. Each sounding of course is subject to the same conditions, or pretty nearly. While I am aware that very elaborate attempts were made to get those soundings accurate, I am not yet entirely satisfied that they do possess the accuracy that is claimed for them, nor am I satisfied that the section at the International Bridge has remained in the condition in which it was when sounded.

Q. Why did you say that there were errors in sounding that would all be in the same direction, so that they would be uniform?

A. I did not say they would.

Q. Then we are still back to the proposition that so far as any element of error is concerned which might not compensate, which would operate uniformly in the same direction, we get back to the under-rating of the current meter, do we not?

A. No, because I think it is quite possible that all the sections might have been—there might be an error in the sounding or in the determination of the area of all the cross section, which would be of a similar sign.

Q. And expressed in volumes of discharge would be—

A. Well, I said it might be 4 per cent. It might be half of that; it might be one-fourth of it.

Q. While it is possible that that thing might have happened, it is hardly within the range of probability that all those soundings, if there were errors, should have all been in one direction?

A. If they are treated in the same manner I think the errors should be in the same direction.

Q. And if the depth were 30 feet that would be an error of over a foot, isn't it, possible error of over a foot?

A. Yes.

Q. In what direction?

A. I was applying that correction to area, not to depth. Of course, if you talk about mean depth, your question is correct.

Q. In what direction would that be?

A. Well, I conceive that it might be in either direction.

Q. So that with the three series of observations made at different times and under different conditions, that is the kind of error which is largely eliminated by compensation?

A. No, I think not, because if the observations were treated alike in all three sections, I would expect the error to go in the same direction in all of them.

Q. In what direction would you expect it to go?

A. Whichever one did go.

Q. It might result in making the measured discharge too large, or it might result in making it too small?

A. It might.

Q. It might result in helping to compensate the error growing out of the under-registration of the meter, and it might aggravate it?

A. Certainly.

Q. Now, about this computation of the error of the cross section and the error in soundings, is it your opinion as an engineer that engineers who understand their business would make errors in soundings which would average from eight inches to a foot, in a depth of 20 to 30 feet?

A. It might be done in swift water.

Q. It might be done. Take the open section of the Niagaga and its lower section.

A. I think it is not likely.

Q. Would not the probability of errors in soundings made in the more quiet water, to which I last directed attention, be

much lower than 3 or 4 per cent., assuming the work to be done by competent, skilled engineers?

A. Well, you must bear in mind that, if I understand the process used, these soundings were corrected to account for the obliquity of the cable. Whether correction was applied to the observations in the slower water, or not, I am not informed. I have no information as to what was done there. I can conceive that in applying that correction they might apply too much or they might not apply enough.

Q. That is conceivable, of course?

A. In applying the correction, of course it is obvious the error could not be greater than the correction.

Q. You would feel yourself pretty competent to make that correction with a fair degree of accuracy, wouldn't you?

A. Not in 50 feet of water, with the velocities that are reported.

Q. Take 20 to 30 feet?

A. That is somewhat easier.

Q. You would think you could do that pretty well, couldn't you?

A. Well, it is pretty hard to tell what sort of a kink the cable will get into in going down through 20 feet, even, of swift water.

Q. You would undertake to do that with a degree of accuracy where you would feel confident of the result?

A. It depends on what you call "confidence." I would expect to do it within 5 per cent.

Q. Or less than that?

A. If I felt sure that I had it within two, I would think that I had done pretty well.

Q. And that is an error which might operate either way?

A. It might, but if the observations were treated similarly, it would operate in one way.

Q. That is to say, it might operate either way, but under a certain process it might all operate the same way?

A. It would in all probability operate in one direction.

Q. So that, after all, when we come to this element of error that is acting in the same direction, whose influence is uniformly in the same direction, we have left just one element of the under-registration of the current meter, do we not?

A. I do not think you have the one; I think you have the question of section, but that one element of under-registration of the meter covers a multitude of evils. There is not only the initial error in rating but there is the possibility of change in the condition of the meter during the observation, and the

possibility of incorrect observations; the effect of oblique currents as well as the effect of disturbed currents, and maybe other things. I do not know that I have completely listed them.

Q. All those operate in one direction or another; they are, in other words, what you engineers call compensating errors?

A. It depends on how they are treated, whether they compensate.

Q. I know, but they are all errors that might be one way or they might be the other?

A. No, I think not, Mr. Wilkerson. A man is not likely to have a meter over-registering a number of revolutions because you cannot very well get in an extra break in the circuit, but you can skip one, and the man, his position may be such, the speed may be such that you should get the break just about the time that you stop your observation. You frequently can drop one revolution or three-fourths of a revolution in an observation; that is quite possible.

Q. That would come in the rating as well as the measurement?

A. It is not so likely to come in the rating as it is in the measurement.

Q. Why not?

A. Because your rating time is usually longer than your measurement at a single point. That effect would be eliminated in your rating, because when you come to plot up your observations and get your line, you take a mean curve for your rating curve; and if any single observation is short, it is corrected in part by its neighbors, whereas you do not have that opportunity for comparison in your actual measurement. I think in your rating that effect is pretty nearly wiped out, when you take a series of different speeds, even if two or three should be a revolution short; and when you get through you reduce the error due to that to a very small fraction; whereas in an observation in a river, if you are short that much, that whole effect is short.

Q. Now, having all these things in mind which may be the cause of inaccuracy, which you say is the error in the rating of the meter, the error made in reading the meter, the error due to the Niagara registration of the meter, and all of these things, is it not your opinion, as an engineer, that if three different series of observations made under different conditions and at different times gave substantially the same result, that

would indicate that those errors were all of a kind which compensated each other?

A. I would refer you to my answer to the original question.

Q. Would not engineers generally so regard that as the necessary effect of the coincidence in the result of three series of observations of that kind; that is to say, that the errors were of a kind which balanced each other to a very large extent, so that in the end the correction that it was necessary to make would be negligible, or substantially so?

A. For ordinary purposes, such a coincidence of results would be accepted as establishing the correctness of the observations in question.

Q. Now your reason for the rejection of the Niagara River measurements, and the conclusions drawn from them, involve, in the first place, the perturbed condition, alleged perturbed condition of the water, and we have been discussing that in going over this subject of current meter measurements. Now, what other thing did you have in mind in rejecting the Niagara River discharge measurements? I am not speaking of the increment now; just the discharge measurements themselves.

A. Well, the reason for rejecting them in the first place was their failure to agree with the discharges of the other three rivers.

Q. I am not speaking of the reasons which you had, or the process of reasoning, in which evaporation, rainfall and all those tangible things have been employed, but I am speaking of things which grew out of the physical condition of the river itself. What else besides the fact that they do not coincide with the process of reasoning did you have in mind?

A. We did not start at that end of the line. We discovered by our comparison of the physical conditions of the lakes that the Niagara did not agree with the other rivers, and we sought for the reason. Whether we have found it or not I do not know. We have offered all the explanation we think of. We may not have explained the fact, but the fact is there.

Q. That is according to the computation you have made?

A. According to my best knowledge and belief at the present moment.

Q. You have been seeking for the reason in the condition of the river itself, and you found the turbulent condition of

the river at one of the cross sections which were measured?

A. Two.

Q. Two of the cross sections which were measured. Do you have anything else in mind relating to the physical condition of the river itself, as distinguished from the St. Clair and the St. Lawrence Rivers?

A. Well, it is all included in that term "turbulence"; the causes for it, of course, are various.

Q. You found, however, another reason for the rejection of the increment as established by the Government Engineers which did not grow out of the physical condition of the river. I understand that was because of the condition of Lake Erie, the so-called tilting of Lake Erie?

A. The reason for rejecting the increment again was that it was entirely out of harmony with the increments of the other rivers, and we sought again for a reason to explain it. We may not have found the explanation, but the fact remains. I think really it is the business of the complainant to explain it, but we have endeavored to help him all we could.

Q. Of course it is not the business of either side to reject what is established by scientific methods according to an approved process and take in place of it a process of reasoning in which inference is piled upon inference, and assumption upon assumption. But you do give some weight to the fact that the discharge measurements of the Niagara River were referred to the Buffalo gage readings, and to the fact, as you say, that at times, the lake being tilted, a given discharge measurement was referred to a gage reading which was higher than the mean lake level, so that you would have a small discharge referred to a high lake level, when it should have been referred to a lower lake level. Do I understand that to be the substance of the point which you make against the use of the Buffalo gage reading?

A. That is substantially correct. I might modify your wording slightly in one or two ways. I think you convey the same idea.

Q. I would like to get clearly what you have in mind. If I have not stated it as you understand it, I would like to know how I am in error as to your idea?

A. Just read the question.

Q. (Question read to the witness.)

A. My criticism of the Niagara increment is in part based upon the fact that on account of rapid changes of level in

the surface of Lake Erie, the discharge is frequently referred to an elevation of the lake which is different from that which actually produced that discharge. And in general, at the high points, the discharge is lower than that corresponding to the elevation indicated, and at the low points, it is higher than that corresponding to the elevation, which has the effect of reducing the increment.

Q. Are you able to give us an expression of your opinion of the discrepancy, in the form of percentage?

A. Yes. Basing my opinion upon the plottings submitted by the complainant as Complainant's Exhibit F, October 8, 1913, and also Exhibits G, H and I, of the same date, I notice that in every instance when a discharge measurement was made at a time when the lake was at a summit, the measured discharge is greater than the computed discharge; and that in every instance when a discharge was measured with the lake at a minimum, the measured discharge is less than the computed discharge, which indicates to me that the increment used by the complainant is certainly too low.

Now, if we take on these charts the observations at the summits, as we go along, take them in pairs, a maximum and a minimum, beginning with Chart 1, I have compared Observation No. 3 on October 21st, with Observation No. 18, which is on October 26th, and I find that the increment indicated there is 28,500.

I then compare Observation No. 20, which is on October 28th, with Observation No. 27, which is on October 31st, and I find the increment indicated to be 55,800.

I then compare Observation 29, which is on October 31st, with Observation 37, which is on November 4th, and I find the increment indicated to be 28,500.

I also compare Observations 27 and 29, which were both made on the same day, October 31st, and I find the increment indicated to be 47,800.

I then go to the next sheet, sheet No. 2, and compare Observations 42 and 43, which were made on June 27th, and find an increment of 51,100.

I then compare Observation 47, which was made on June 30th, with Observation 53, which was made on July 2d, and which evidently does not represent a minimum, but was put in there because it gives a good long range, and get an increment of 36,500.

I then compare Observation 55 with Observation 58, both being on July 6th, and get an increment of 29,700.

I then compare Observation 70, which is taken July 16th, with Observation 72, taken July 18th, and get an increment of 57,100.

I then compare Observation 88, which was taken July 24th, with Observation 93, which was taken July 25th, and I get an increment of 78,500. The average increment of all these comparisons is 45,944.

In view of that, these being taken at times when the lake was changing its position, having previously been either rising or falling, and now changing in the opposite sense, it might be considered therefore to be stationary, or in one case taken where the lake appears to have been stationary for some time before, it sems to me to be a pretty reasonable method of getting at an increment. I think this indication of 45,944 is so far above that which the complainant has derived, and these plottings show the observed observations to deviate so uniformly above for the high points, and below for the low points, that is the computed discharges, that I feel very well satisfied that the complainant's increment is in error, and that the increment arrived at by myself, by other processes, is more nearly correct than theirs.

Recess to 2 o'clock p. m.

After recess, 2 o'clock p. m.

GARDNER S. WILLIAMS resumed:

(Last paragraph of witness' answer previous to recess read.)

The Witness: And making an allowance for those errors of individual observation which are aside from constant errors, this result seems to indicate that the complainant's increment is in error by between 50 and 75 per cent.

Mr. Wilkerson: Q. And you have reached that conclusion from a study of the observations which were plotted upon the chart which was shown to you on yesterday, independent of any other consideration?

A. Oh, no, not independent of any other consideration, but mainly—no, I will not say mainly.

Q. I want you to confine yourself now to the chart that was shown you on yesterday; limit your conclusion merely to the observations as there plotted upon the chart which was shown to you on yesterday, and I ask you whether or not, upon what appears upon those charts themselves independent

of any other consideration, there is any basis upon which an engineer can predicate the statement that the increment derived by the Government Engineers is from 50 to 75 per cent. in error, in your opinion? I want you to limit this solely to what appears upon the chart.

A. I think that is indicated by the information on these charts.

Q. That is your conclusion and judgment, as an engineer?

A. That is what they indicate to me at the present time.

Q. You have been studying them, and you have no doubt that you have given that subject all the thought that it ought to be given prior to making a statement of that kind?

A. I see no reason to change the statement.

Q. Well, have you anything in mind that might lead you to change it in the future?

A. Erroneous plotting of the observations.

Q. That is all?

A. The erroneous plotting of the computations. I have not checked any of those things.

Q. You picked out this morning for us some sets of observations, in which you offset one observation against another?

A. Yes.

Q. And by a comparison of two of the observations, you got a very high increment. And your conclusion was based upon the high increments which were shown by putting one observation against the other, by separating sets of observations. You could have picked out from the same sheet, had you started out to do so, could you not, sets of observations which would have shown an increment much less than 22,000 cubic feet?

A. It would have been rather difficult to have attached those observations definitely to a stage of the lake.

Q. You could have picked out sets of observations, had you seen fit to do so, which would in fact show a negative increment, could you not?

A. That could have been done, yes.

Q. Do you undertake to say as an engineer that a method of deriving an increment by comparing sets of two observations in the way in which you did this morning is a correct way of deriving an increment from a series of observations?

A. I undertake to say that in a series of observations, it is wise and proper to select those which indicate that they represent most truly the natural condition, and it may be

that in a set of observations there might be one hundred and only one of them worthy of consideration. The fact you have a mass of observations having no better conditions does not make that mass good.

On these plates, Exhibits F, G, H and I, we have the computed discharge of the Niagara River and we have the observations plotted. It is very peculiar that wherever they have a maximum, in almost every case, and have at the same time, or in that vicinity, a measurement, that measurement exceeds the maximum; and wherever they have a minimum, in almost every case, and have a measurement, that measurement is less than the minimum, which indicates clearly that the increment used in computing that curve is too small.

Q. Isn't it a fact those two things compensate?

A. Do not compensate at all in determining the increment.

Q. That is your opinion?

A. Yes. I can see no reason why, when they had a high stage the measurements were high, and when they had a low stage the measurements were low, I can see no reason why they should compensate.

Q. You say they do not compensate?

A. I say they do not as far as the increment is concerned.

Q. That is to say, they indicate, when the lake is at a high stage, or going up, the observation as actually observed is higher than the computed?

A. It indicates that when the lake is turning from a rising to a falling stage, at the point where it forms a cusp, or the maximum, the observed results are greater than the computed.

Q. And when it is going down?

A. When it is changing from a downward to an upward stage, the observed are less than the computed.

Q. And those two do not compensate?

A. They do not compensate as far as the increment is concerned.

Q. You say in order to get a correct increment, your observations should be taken under normal conditions?

A. I think so.

Q. What do you understand to be the normal condition of Lake Erie with respect to the Niagara River, is it quiescent, or is it going up and down most of the time?

A. I have not been able to discover. You can, however, utilize similar conditions.

Q. Assuming that these charts which were shown to you

yesterday are accurately plotted, are you able to get any light on that subject as to what is the normal condition of Lake Erie?

A. I should say its normal condition was vibrating.

Q. About 90 per cent. of the time, isn't it?

A. I guess all the time.

Q. So that if you wanted to take the lake at its normal condition, you would take it as it was going up and down, and the flow of the river with reference to the lake when going up and down?

A. Not in determining the increment, however.

Q. You would take it then for the purpose of determining the increment at the abnormal times when it is in a comparatively quiescent condition, would you?

A. In determining the increment, it is necessary to connect the discharge with the lake stage at a certain time and a certain place, because your increment is dependent upon the difference of elevation of your lake. If you do not get that difference correctly, you do not get your increment correctly.

Q. Now let me direct your attention, Mr. Williams, to two sheets that were produced yesterday, one being sheet 2, one curve series, marked Exhibit K, October 8, 1913; and the other being sheet No. 3, of the three curve series, marked Exhibit H, October 8, 1913.

I direct your attention to the observations plotted on Exhibit K for November 4, 1899, and ask you to note there the level of Lake Erie at Buffalo was approximately 573.3; the mean lake level at Cleveland, the monthly mean, 571.62; the discharge, approximately 220,000. The curves drawn there indicate a tilting up of the lake, do they not?

A. It indicates high water on November 4th, apparently. I should say that the lake was tilted, yes.

Q. As compared with the level at Cleveland, 571.62?

A. Yes.

Q. That is a tilting up of the lake?

A. Yes.

Q. Take the observations for July 31, 1908, on Exhibit H, the same being sheet 3 of the so-called three curve charts. I direct your attention to the fact that the elevation of Lake Erie, 573.32, the figure which I just gave you, is the mean lake level at Cleveland; the curve showing at the Buffalo reading was very slightly below that. The discharge observations for that day show approximately 220,000. I ask you

to observe there was obviously a quiescent condition of Lake Erie.

A. The observations of that day, as I should read them, would show considerably more than 220,000 on that occasion.

Q. 225,000?

A. That is better.

Q. The other one shows about 222 or 223,000, on the other sheet. Now, assuming the accuracy of the work of plotting these observations, would that indicate to you as an engineer that that which controls a volume of discharge is the elevation of the lake at the particular time at Buffalo, without regard to whether the lake is tilted or not? I will limit my question to this particular instance.

A. Just how does that question terminate?

Q. (Question read.) That is Lake Erie.

A. No, it does not, for the reason that the observations on July 31st fall considerably further away from the computed discharge which is based upon the simultaneous elevation, or nearly simultaneous elevation of the lake than do those of November 4th. For that reason, it appears to me that it does not indicate that they are controlled by the same conditions.

Q. I do not understand your answer. Just restate that.

A. (Answer of witness read.)

Q. By that you mean on July 31, 1908, we have two observations that seem to be right together?

A. You have four observations that day, and I was considering them all.

Q. You refer to the one being made in the forenoon of that day?

A. I was referring to the observations made on July 31st.

Q. You are considering them all, and you say they are further away from the computed line than the other?

A. Yes, showing a higher discharge.

Q. How much further away are they? If you averaged the ones on July 31, 1908, there is a difference of more than 2,000 cubic feet, is there not?

A. Somewhere around 3,000 cubic feet it is.

Q. Between two and three thousand?

A. I should say it was over three, but I may be in error.

Q. That would not be 50 or 75 per cent. of 220,000, would it?

A. No, nobody intimated it would be. I say the incre-

ments were from 50 to 75 per cent. in error. That is very different from saying the discharges were.

Q. It would not be 50 or 75 per cent. of 22,000, would it?

A. Let's see, what is it?

Q. It would be about 10 per cent.

A. That is only one end of your scale.

Q. Take the observations now for July 23, 1908, on the three curve chart. Your monthly mean lake level at Cleveland is 573.32. The elevation at Buffalo is 573.2 approximately. The reading is 222,000, and there are four observations for that day, all of which are practically on the line.

A. All of which are slightly above the line. Start with 83, which was the first; what was the elevation that caused that, a reading an hour or so later or the one before?

Q. Take all of them.

Mr. Shenehon: At the time.

A. At the time, then it is above; it is above by at least 2,000 feet.

Mr. Wilkerson: Q. Which one is that?

A. The first one.

Q. It does not look to me to be more than 1,000 feet above.

A. I am trying to get the times you represent these.

Q. Isn't it a fact that it is hardly more than 1,000 feet?

A. I think not, according to this scale, if the center of the dot is plotted right. I assume that the position of the measurement is represented by the center of the dot.

Q. What do you say about the second one, how much is that?

A. About 2,500.

Q. The third one?

A. About 1,500.

Q. And the fourth?

A. Something over 1,500, and always larger.

Q. Now, going back to November 4th on the one curve series, how much is the plotting there above the line, looking at it the way you have looked at these other observations, about which you have just testified?

A. About a little over 1,500.

Q. Look at that straight, the way you did the other ones. It looks to me to be like 2,500.

A. I would say it is under 2,000, slightly nearer 2,000 than it is 1,500, but it is still high.

Q. Expressed in either case in percentage of volume of

discharge, it would be a very small percentage, wouldn't it, 1 or 2 per cent.?

A. One or two per cent. covers them.

Q. It would be 1 per cent. in the last case?

A. In the last case.

Q. Now I understand that one of the points of difference in the method which you used in deriving your increment for these different rivers, and the method which is used by the Lake Survey and the Government Engineers, consisted in referring particular discharge observations to a gauge reading which was 24 hours before the time of the making of the discharge measurements?

A. I think not.

Q. Perhaps I should have said groups of observations.

A. No, that is not correct exactly. The elevation producing the discharge was assumed to be the elevation of the period over which the observations extended, with one day added at the beginning, so that if you had a period of 10 days, if the observations covered 10 days, the period over which the elevations are computed would cover 11, if I remember correctly.

Q. And you subtracted one day from the end?

A. I think not. I was under the impression we had carried it through the full—those were not advanced 24 hours; we took in the elevation the last day in every case, I think.

Q. As a preliminary to what I am going to ask you, let us have just what you did to shoving these days back, so far as—

A. We did not shove it back, we did not shove the day back. We added one day at the beginning, which would be equivalent, of course, to shoving the center of the group that determines the elevation half a day, 12 hours.

Q. Twelve hours?

A. It really has the effect of shoving it 12 hours.

Q. So that the observation is, in fact, referred to an elevation of 12 hours—

A. Twelve hours previous.

Q. —previous to the time the observation is made?

A. That statement is not exactly right. The elevation which is assumed to control the discharge has its center of gravity 12 hours earlier than the center of gravity of the measurements which I have included in the group. I presume that is what you mean.

Q. There is a slight difference between the two, but it is not a material difference?

A. I think the understanding of counsel was substantially the same as my method of procedure.

Q. Now take sheet 1, for instance.

A. Of the three curve series?

Q. Of the three curve series. Have you considered the elevations of water surface of Lake Erie at the Buffalo gauge, as compared with the elevations of the water surface in the gorge pool of the Niagara River at Suspension Bridge gauge, for the purpose of seeing how long it takes the effect to travel from one point on the river to the other. (Handing witness Exhibit G.)

A. I have, and also the relation between the Buffalo gage and the Chippewa gage, which is somewhat nearer the outlet of the lake.

Q. How long does it take the effect to travel from the Buffalo gage to the Gorge Pool?

A. Four to six hours apparently, usually. In some instances it may take a little longer, and some will come a little more rapidly. Of course sudden changes, large changes would travel more rapidly than smaller ones.

Q. Let us take Sunday, November 3d, on Exhibit G, Sheet 1.

A. Sunday, November 3d, Sheet 1?

Q. Yes.

A. What is the question?

Q. You notice the peak of the line?

A. Yes, that is four hours.

Q. In the upper column. Now, take October 25th.

A. Four hours.

Q. Would you say three or four?

A. Four hours. I think the range that I gave covered it. I said six to four; some occasions longer, some a little less. I think I did find one that was as low as three hours.

Q. The open section and the International Bridge section are nearer the Buffalo gage than this Gorge Pool?

A. Yes.

Q. So it would not take so long to travel?

A. Assuming this represents the time it takes the full effect to travel, which is not the case for the lake does not stay stationary long enough for the full effect to be felt there; you would find, for instance, when it had been lowering if it would stop at some elevation, the water in the pool would continue to drop for some time after the period indicated here, and then of course would remain stationary, so that this wide vibrating lake-like expanse below never corresponds completely

to either the low or the high point that is reached by the controlling body.

Q. If you took a discharge observation which had been made on Sunday, November 3d, in the morning, and referred that to a gage reading 12 hours earlier than that, it is perfectly obvious that you would have your discharge measurement referred to a gage reading which would give an erroneous result, isn't it?

A. It would be entirely incorrect to refer a single observation in that way; and such reference could only be properly introduced in groups; and in the light of the information that has come into my hands for the first time within the past 60 days, it is my opinion that the setting back of the time of observation 24 hours, or the center of gravity 12 hours, is too far for the Niagara River.

Q. How much too far?

A. That is a somewhat difficult question to answer.

Q. Do you think it is so much that setting it back 12 hours would make a very material difference in the result obtained by referring——

A. Not in the average of a series of days.

Q. An allowance of three or four hours would be sufficient?

A. For individual observations I would say that setting back an hour is probably about as much as you need.

Q. Setting it back an hour?

A. For individual observations and they would cover all that is warranted in dealing with individual observations.

Q. If you average your center of gravity, it would be an hour or more later?

A. No. It is my opinion you cannot deal with individual observations and get a satisfactory increment because as I stated before no observation represents the discharge of the elevation to which it would then be referred.

Q. To further illustrate that, look at your Table 45A, Sheet 5, and also look at Sheet No. 3 of the one curve series, Exhibit L, October 8, 1913.

A. What is the inquiry?

Q. I direct your attention to group 12. You find those observations plotted on the chart which I directed your attention to, do you not, Sheet No. 3 of the one curve series?

A. June 27th and 30th, yes.

Q. There are six of them plotted?

A. There are six observations, yes, sir.

Q. You notice that the day before there was low water apparently. What I was going to say was—and I want to get

it into the record—that illustrates what you have said about the propriety, or rather the impropriety of referring those back 12 hours. That is all I wanted to direct your attention to. That is a concrete illustration of how that might work?

A. What is it?

Q. That is a concrete illustration of how it might work, if you referred them back 12 hours?

A. But it will be found if you refer them back 12 hours, or refer them to the actual time here, the difference will not be very material. You would have 2.65 instead of 2.62, which makes a difference of .03 of a foot.

Q. Now another point of difference between yourself and the Government Engineers in the method of deriving this increment consisted in weighting the observations. And by referring to Sheet 1 of this three curve series, the same being Exhibit F, October 8, 1913, I direct your attention to the fact that on October 26, 1907, you have four observations. They are plotted there; and, for example, on October 30th, you have one observation.

A. What is the question?

Q. I have directed your attention to the fact that on one day you have four observations and on the other day you had one?

A. Yes. You are referring to the 29th and 30th?

Q. I am referring to the 26th and the 30th.

A. All right.

Now as I understand your method, you took the four observations that were made on the 26th and averaged them and gave to that average the weight of one?

A. Yes.

Q. And you give to the sole observation on the 30th, the weight of one?

A. Yes.

Q. Equal to the average of the four observations?

A. The average on the basis of time, assuming the observations to be correct.

Q. Now then if according to your method on the 26th of October, 1907, there had been only one observation made, namely, the one which is on the line 343.0——

A. That is the lowest one?

Q. The lowest one, you would have given that a weight of one?

A. I would have given that a weight of one.

Q. The same weight as you would the other?

A. Exactly. That is the only thing we could do, it being all the information we have.

Q. If you had the highest one, you would give that the weight of one?

A. Certainly. If you only had one that day, it would have had the weight of one.

Q. Now, take Sheet No. 2 of the one curve series, Exhibit K, October 8, 1913. Look at the observations for October 21st, and then the observations for the 22d, 23d, 24th, 25th, 26th and 27th.

A. What was the day?

Q. October 21st down to October 27th. Now, according to your method, if you were considering a group of observations commencing on the 21st and ending on the 27th, you would take the average of the two on the 21st and give that a weight of one; and the average on the 27th and give that a weight of one; and then you would give the whole thing a weight of how much?

A. I would not apply such a method as that, because there is too much intervening space; at least I doubt if I would, although the elevation is comparatively uniform. It is possible I might use such a case as that; in that case, the group would have the weight of the time over which it is extended.

Q. You say it is comparatively uniform. You regard a difference of 10,000—speaking of discharge now—a difference of elevation would make a difference of discharge of 10,000 cubic feet, you regard that as being comparatively uniform, having in mind the whole situation?

A. It is so far as the accuracy of the evidence presented in this case is concerned. That would only mean a variation of somewhere around three-tenths of a foot, which is not a high one.

Q. It is evident, isn't it, Mr. Williams, that this method which we have just been illustrating here, by pointing out this specific instance, applied to any series of observations of this kind would necessarily result in producing a greater increment than the method adopted by the Government Engineers?

A. Not necessarily. It might produce a less one.

Q. It is hardly conceivable it would; it is hardly conceivable you could get a set of observations where it would be less; it would have to be most extraordinary and the groups would have to be most extraordinarily selected?

A. It is hard to conceive that any one could get a lower increment by any process than the Government Engineers have presented, but the fact as to one method or another giv-

ing a higher or lower result is not established in the method at all.

Q. It gets a larger result for the St. Clair, doesn't it?

A. It does.

Q. It gave a larger result for the St. Lawrence?

A. It did.

Q. As applied to each series of observations produced, or any group of observations which you have been able to make. In your studies of this case, did you strike a set of observations which if you applied this method of weighting observations to, gave an increment which was lower than that of the Government Engineers?

A. No, sir, I did not, and I do not think that you could select observations from here, in any way, and apply them to the elevations and get a lower increment than the Government Engineers have gotten, if you make a uniform increment for the whole range.

As far as selecting observations is concerned, they were selected solely upon the uniformity of lake levels during the period which was covered, as that uniformity was indicated by the mean daily elevation, which was all we had to work from. If we had had this information which we now have, we might have made different selections.

Q. I don't remember whether you were present or not when Mr. Freeman testified, Mr. Williams?

A. I think I was.

Q. You recall his testimony; you have read it at any rate?

A. I have not read it.

Q. I read you a paragraph from his testimony as follows, speaking of the ice effects in the St. Clair River; he says:

"These ice effects were observed with considerable care by the United States Engineers only in the year 1901, and at that time periods were found when the flow of the river was cut down about one-half. A reference to this may be found in the report of the Chief of Engineers for 1902, on pages 2835 and 2836.

On the other hand, in winters like that which we have just passed through, there would be little or no clogging of this kind. Obviously when the St. Clair River is thus clogged, Lakes Huron and Michigan must rise, and Lakes St. Clair and Erie must fall, because of the cutting off of their most important source of water supply. Lake Erie doubtless also suffers some impediment to its discharge, because of ice in the Niagara River. But the records indicate that the extent of this clogging is far less than in the St. Clair River.

Perhaps this is as good a place as any to go into this question of ice obstruction, in some detail. I regard this matter as extremely important, because I am led to believe that failure to appreciate its influence has led to serious error in the studies of the levels of the Great Lakes by the Government Engineers; and to the best of my judgment and belief, sufficient compensation for its effect has not been made in their computations and estimates of the yearly discharge of the several lakes, and in the relation of their levels."

You have given some attention to that subject, have you?

A. Somewhat.

Q. What do you say as to the correctness of the observations which are there made by Mr. Freeman?

A. I think they are correct substantially.

Q. Have you given consideration to this ice effect in your studies that you have presented here?

A. You mean as to determining increments?

Q. Yes.

A. I have not. I have followed the Government Engineers in that, as we were dealing with the facts which they presented.

Q. You have made in this case, Mr. Williams, a study of the physical conditions of the Great Lakes and rivers, in order to determine the consistency of the flow of the three rivers, taking account of rainfall, run-off, evaporation, reservoir effect and river flow. In that analysis, which you presented here, did you consider the winter conditions of the flow of the various rivers, the St. Clair, Niagara and St. Lawrence?

A. Not in the analysis as presented.

Q. I mean in your testimony?

A. In the testimony up today, I have not.

Q. That has not been taken into consideration?

A. (No response.)

Q. Is it not a fact that that should be taken into consideration?

A. Possibly it should be; however, it does not materially modify the results obtained.

Q. But you did——

A. I did examine it, to ascertain whether it would make an important difference.

Q. When did you do that?

A. Oh, I did that several months ago; in fact, I guess over a year ago, and found that it made very little difference, and for that reason did not introduce it inasmuch as definite information on it had not been introduced on the other side.

Q. Then Mr. Freeman is a little extreme in his statement of the effect of those ice conditions, isn't he?

A. I think not, when he is considering the effect upon navigation, which I assume is the condition to which he is referring.

Q. No, he is speaking of the effect on the condition of the rivers.

A. With reference to the work of the United States Corps of Engineers, which, as I understand it, has to do with navigation.

Q. Well, with reference to the effect on the outflow of the rivers?

A. Their only reason for having anything to do with it is on the ground of the Commerce Clause in the Constitution, as I understand it.

Q. I do not see why it should have been important from his standpoint, and not important from yours. Is it your understanding you have been studying this case from one point of view and Mr. Freeman from another?

A. Not at all, but I say it is unimportant as to the relations of the discharges of the several rivers.

Q. You are familiar with the statement as to the effect of ice in the St. Clair River during the winters of 1900, 1901 and 1902, appearing on page 2837 of the report of the Lake Survey, 1900, 1902?

A. I have the reference.

Q. Does that indicate to you that in the physical study of a river you cannot leave out of consideration the ice effect?

A. It depends altogether upon what the purpose of your investigation is. In dealing with a long period of years, you find that ice effects in one river compensate for the effects in another. The effect in your final result is not material whether you should take them specifically or not, if you are dealing simply with the relations between one river and another.

Q. You found that to be true as between the St. Clair and the Niagara, did you?

A. I find that to be true between the St. Clair and the St. Lawrence; and I can see no reason from my own personal observations why the conditions that exist in those two rivers are not substantially duplicated on the Niagara, and from inquiry I have learned, from the testimony of those familiar with the situation, that those conditions are to a very large extent duplicated.

Q. Where did you get that information; what is your authority?

A. Some of it from Mr. Emil Kuichling; some of it from Mr. Louis H. Knapp; some of it from my own personal observation; some of it from Mr. Freeman.

Q. Did you ever get any information of that kind from any report of the Government, or from any statement by anyone who had made a continuous observation of the situation, in the discharge of his duty?

A. I am not aware of any government discussion of the subject.

Q. Now, if you have, in your physical study of these rivers, assumed this ice condition in the Niagara to be as you have stated when as a matter of fact it is different from your assumption and understanding on the subject, then your physical analysis of these rivers would be subject to the necessary correction on account of that assumption, would it not?

A. A rather moderate correction, because the effect of ice when distributed over a period of years, it is very small; in a single year it may be very great, but when you distribute it over a considerable period, it is quite small.

Q. In the St. Clair River, during the winters of 1900, 1901 and 1902, as shown on page 2837 of this report, of the Chief of Engineers for 1900, 1902, there is a loss over the full year, in 1900 of over 12,000; 1901, more than 20,000; 1902, almost 10,000, is there not?

A. I call your attention to the fact these are based on observations for the year 1901 only; that the rest are computations. Those investigations have been discussed in another report at a later date. And I will call your attention to page 4107 of Appendix EEE of the Annual Report of the Chief of Engineers for 1904, in which there is a table showing the St. Clair River monthly mean discharges in cubic feet per second, referenced to the report of 1902, giving the ice effect as shown by that report, and as determined by this subsequent examination in which the discharge both of the St. Clair River and the Detroit River was considered; and whereas in the 1902 report the ice effect is given as 30,300, in the 1904 report it is given as 8,070 for January.

For February, in the 1902 report, it was given at 85,900, and in the 1904 report as 34,070.

For March, it was given in the 1902 report as 53,800, and in the 1904 report as 18,970.

For April, it is given in the 1902 report as 66,300, and in the 1904 report as 56,770.

For May, the ice effect is given in the 1902 report as 11,800, and in 1904 report as 16,770. And in commenting, the report says:

"The method of deriving the quantity of water held back by an ice gorge as given in the 1902 report dependent on the relation between the restricted discharge and the slope at the head of river as observed in some particular year is not a method strictly applicable to other years, unless the ice obstruction is located in the same part of the river. The relation of slope to discharge must depend upon the location of the obstruction. For this reason it is believed the computed discharge of the Detroit River is a better measure of the quantity of water passing through the St. Clair River during the ice gorges than any derivation based on slopes over short stretches of the river. The determination by the Detroit River is by no means certain. When there is a gorge in the Detroit River the gage readings give an erroneous result for the discharge. Ice gorges in the Detroit River are, however, less frequent than in the St. Clair."

In view of that, it has seemed to me it was hardly wise to include the full effects indicated in Table No. 7 of the Report of 1902.

Q. There still remains, however, some effect?

A. Some effect.

Q. And the necessity of giving that effect some consideration?

A. Yes, sir, and it was given some consideration.

Cross-examination closed.

Adjourned to Friday, October 10, 1913, 10:30 a. m.

Friday, October 10, 10:30 a. m.

Parties met pursuant to adjournment.

Adjourned to Saturday, October 11th, 10 a. m.

Saturday, October 11th, 10 a. m.

Parties met pursuant to adjournment.

GARDNER S. WILLIAMS, resumed the stand and testified further as follows:

Re-direct Examination by Mr. Austrian.

Q. Mr. Williams, you were interrogated by counsel for the Government with reference to your compensation in this case. The compensation paid to you by defendant in this case was in no wise dependent upon the result or outcome of this litigation?

A. Not at all.

Q. Prior to your employment by the defendant in this case, were you approached by the complainant, with reference to becoming employed by it in this case?

A. I was.

Q. Did you accept a proffer of employment by the Government?

A. I did not.

Q. You have been interrogated with reference to certain testimony given by you in the case of the State of Missouri——

Mr. Wilkerson: When you say the Government, I assume the Government is a creature of many arms. It might be well to say who.

Mr. Austrian: I have no objection.

Mr. Adcock: He has the correspondence.

The Witness: To state the thing clearly, I received a letter from Major Keller, asking me if I would be available to serve the Government in this case.

Mr. Austrian: Q. Who is Major Keller?

A. Major Keller was the engineer in charge of the Lake Survey office in Detroit at that time. The letter stated that he was acting under the authority of the United States District Attorney. And I replied to that letter that I was considering an engagement with the Sanitary District, and that if my views proved acceptable to them, I should take that side of the case; and thanked him for the compliment and declined the case.

Mr. Wilkerson: That is at the time you got the major's letter, you were already negotiating with the Sanitary District?

A. I had had correspondence with the District. At the time

I referred to this letter before, I was not clear on the subject, and my testimony would indicate that I had not had any correspondence with the District. But on referring to my files, I found that I had entered into correspondence with the District, although no engagement had been made with them, at the time I declined the engagement with the Government.

Mr. Austrian: Q. Counsel referred upon your cross-examination to some testimony that you had given in the case of State of Missouri versus the State of Illinois. Have you that testimony in mind?

A. I have in a general way.

Q. I desire to direct your attention particularly to that part of your testimony in which you refer to the danger of infection to the people and to the stock of Missouri, on account of anthrax and cholera germs being carried by means of the channel into the lower waters, into and about the State of Missouri.

A. I have in mind that testimony.

Q. Were your conclusions as there stated based upon any assumptions?

A. Well, they were based upon the assumption of the existence of anthrax in the vicinity of Chicago, or the existence of the diseases considered in such locations as to permit of the germs being distributed through the sewage of Chicago into the Drainage Canal.

Q. Since the opening of the Drainage Canal, from your observations, what if any conclusions have you reached with reference to that subject?

A. So far as I have been able to learn, and I have had the subject more or less in mind, there has been no indication of an outbreak, of a serious outbreak of water borne diseases in the State of Missouri due to anthrax, or the particular germs considered in that answer; nor do I know nor have I learned of their existence at Chicago.

The testimony at that time was given in the light of the best information that I had in regard to the transmission of disease germs, which was necessarily based to a considerable extent upon the observations of the life of such germs in various kinds of water, and the transmission of typhoid fever; particularly in some streams in New England, in the St. Clair River, and in the Red Lake River in Dakota. There was nowhere available information upon a case similar to the specific one which we have to deal with here, and no one appreciated the importance, or at least I did not, and I think very

few of us appreciated the importance of the excess of oxygen which is contained in the Lake Michigan water.

It is very considerably higher than in running streams, and on that account is of especial value in the reduction of sewage products.

Mr. Wilkerson: Q. That is it will take care of more sewage products than ordinary water?

A. Yes. On account of this, the results of the drainage works have apparently been much better than was anticipated, at the time the testimony was given.

Mr. Austrian: Q. Mr. Williams, bearing upon the subject of the amount or the quantity of oxygen in Lake Michigan waters, do you draw any conclusion from the present state of the fish in the Illinois River as compared to that in the stream prior to the opening of the Drainage Canal?

A. Though I have no personal knowledge of the conditions, it is my understanding from the reports and statements which have come to me regarding it, that there has been a large increase in fish life in the Illinois River since the opening of the Sanitary Canal; and this would indicate an increase both in the food supplies and in the oxygen supplied in the river—supply of free oxygen.

Mr. Wilkerson: If that should be material, that issue in this case——

Mr. Austrian: We will prove that the fish industry has increased 300 per cent.

Mr. Wilkerson: It is not competent evidence. It does not occur to me it is at all material to any issues in the case.

Mr. Austrian: It is a matter of public knowledge that the fish industry in the Illinois River has increased between 250 and 300 per cent.

Q. At the time that you testified in the case of Missouri versus Illinois, you had in mind did you not the general character of the work that the Drainage Canal would perform?

A. I did.

Q. Since the opening of the canal, and from your observations and studies of the subject, has the Drainage Canal performed its purposes as well or better than you anticipate?

Mr. Wilkerson: I object to that as not proper re-direct, and as the statement of a witness who is not qualified to testify on the subject; and not only that, but it is stating certain things which he had in mind which were accomplished. We do not know what he had in mind.

Mr. Austrian: I desire to supplement that question by this question:

Q. The testimony which you gave in that case, to which your attention has been directed by the Government, was in the light, was it not, of the work which you anticipated the Sanitary Canal would perform?

A. It was.

Mr. Austrian: Then I will put the pending question.

(Question read as follows: "Q. Since the opening of the canal, and from your observations and studies of the subject, has the Drainage Canal performed its purposes as well or better than you anticipated?")

A. So far as disposing of the sewage wastes of Chicago, the performance has been substantially what was expected, namely, the removing of them from a location where they threatened the purity of the water supply of Chicago. So far as their affecting the quality of the water in the Mississippi River, judging from the vital statistics of the communities which were in locations to be affected, it appears that the purification taking place in the sewage, as it passes through the Drainage Canal to the Des Plaines and Illinois Rivers is better, more complete, than was anticipated at the time the testimony in the St. Louis case was given.

Q. When you say was anticipated, you mean was anticipated by you, among others?

A. I mean was anticipated by me, referring to my own testimony.

Q. Does the mere fact that the current meter method of measuring large streams is the only available one known give any evidence or indication of the accuracy of that method, in your opinion?

A. I can't see that it does.

Q. In your cross-examination, Mr. Wilkerson called your attention to certain observations which were made during the time when there were ice conditions in the Niagara River included in Table No. 3 and other tables of Exhibit 34. Have you made any correction in those tables to meet the corrections or criticisms indicated, and if so what corrections have been made, and with what result?

A. Table 3 of Williams' Exhibit 34, the observations objected to, have been canceled by black ink lines; and the resulting computations have been—the original computations have been canceled with black ink lines; and corrected computations inserted in black ink.

The result of excluding the observations which were made during the winter shows the average variation from the mean of the mean discharge of the Niagara River at the Bridge Sec-

tion to be .872 per cent., as against 1.202, with the observations in.

There has been added Table 3 A, consisting of three sheets, which includes not only comparisons in the original series of observations covered by the original Table 3, but also comparisons with the observations of 1907 and 1908. This computation, considering all the observations made at the International Bridge, and comparing those made under similar conditions, gives an average variation from the mean of 1.007 per cent. of the mean discharge, still showing that the Niagara observations, by this comparison, are not within themselves as consistent as those on the St. Clair, as was heretofore testified.

In Table XLV, the group including the winter observations has been stricken out by a white line across the blue print, and the footings have been stricken out in a similar manner and the new results, corrected results, have ben inserted.

The same has been done in Table XLV A on sheet 2; on Table XLVI, Table XLVI A, Table XLVI B, Table XLVII and on Table XLVIII A, so that these tables show the original figures with a line drawn through them to indicate those that are in error, and the corrected figures added below; and, in general, the effect upon the increment was to reduce it about 1,500 cubic feet a second.

I would suggest that this corrected set of tables, which also contains now an index, be substituted for the Exhibit 34.

Mr. Wilkerson: The one which you have made is omitting the winter observations?

A. I have omitted the winter observations.

Q. And you have recomputed the increment according to Williams' Exhibit 34 and marked Williams' Exhibit 34, and the same method which you used when the winter observations were included?

A. Yes.

Q. So that the table on its face shows—

A. That it was in error in the first place.

Q. Shows what the first figures were, and what the second are?

A. Yes.

Mr. Austrian: It is agreed this may be substituted for the original Williams' Exhibit 34 may be withdrawn from the record.

Mr. Wilkerson: Very well.

Mr. Austrian: Q. Mr. Williams, what is the difference

between the method adopted by you in the application of rainfall records and the method attempted to be used by the Government, in connection with certain of the exhibits which have been offered for identification, on your cross-examination on October 8 and 9, 1913?

A. The method of the Government in applying its rainfall data seems to have been considered the rainfall for a single year as a unit, whereas in the application of the rainfall data as I have used it, I have considered the effects of a series of years. The effect of the rainfall is influenced by the manner in which it operates. Two years may have exactly the same rainfall and produce materially different results, on account of the distribution of that rainfall through the year, so that if it is intended or attempted to make use of the rainfall record of a single year, a study must be made of the distribution of that rainfall during the year, oftentimes goin back so far as to consider the daily distribution, in order to arrive at safe conclusions. When, however, it is possible to take a group of a number of years, these variations from year to year become eliminated in an average, upon which it is much safer to predicate results and which have been known, in many cases, to permit the drawing of very accurate and reliable conclusions.

In my use of rainfall data I have confined myself, so far as I can now recall, in this case, to averages for periods of years, for the very purpose of eliminating the possibility of erroneous conclusions being drawn from an abnormal condition in a single year.

Q. What, if any, comment have you to make as to the propriety of applying an increment derived from Lake Erie in its fluctuating state, in the determination of the effect upon that lake by the Chicago diversion?

A. The criticism would be this: The Chicago diversion will be substantially a constant and continuous effect. The quantity of water taken, while it necessarily varies somewhat from day to day, is in general an approximately constant quantity. The determination of an increment from Lake Erie, in that condition in which it exists for perhaps 90 per cent. of the time, while it might be satisfactory for some purposes, though I can hardly conceive now what, is decidedly inapplicable to a case where the quantity to be measured is a constant one.

In other words, we might say that it is the case of trying to determine a constant and continued and finished effect by

comparison with a variable instantaneous and incomplete one.

Mr. Adcock: Q. When you say the fluctuating state, you mean the oscillation?

A. The oscillation from hour to hour.

Q. You did not refer in that to the mean annual?

A. No.

Mr. Austrian: Q. In your opinion, should the Niagara measurements be discarded?

A. They should.

Q. Will you state your reasons for this conclusion?

A. The reason is that considering the lake system as a whole, while the St. Lawrence, Detroit and St. Clair observations agree with the observed facts of the conditions of the Great Lakes, the Niagara observations do not. And the Niagara observations contradict flatly the proposition which is uncontrovertible that where the quantity of water handled is within reasonable limits, the increment must be inversely as the variation in the annual stage of the lake surface. The variation in the mean annual stage of Lake Erie is less than that of Lakes Huron and Michigan; therefore its increment must be larger. The variation of mean annual stage of Lake Erie is also less than that of Ontario, and therefore its increment must be larger than that of Ontario.

In view of these physical conditions, and the fact that the Ontario increment, the St. Clair increment, and the discharges measured in the Detroit River check each other, and the Niagara observations have nothing to support them, it is my conclusion that the weight of evidence is against the Niagara observations, and they are therefore discarded by me.

Re-cross Examination by Mr. Wilkerson.

Q. In what you have said on your re-direct examination, with reference to the discarding of the Niagara observations, you have assumed that the exhibits relating to the subject of the new measurements were accurate, and have given consideration to that in your answer?

A. In giving that answer, I have not given consideration to the new measurements, for the reason that I know nothing of them.

Q. So that if it should appear that the observations as made, and the computations from them, fully warrant what is

shown on the face of those exhibits, you might wish to modify your statement?

A. I might change my view.

Adjourned to Monday, October 13, 1913, 2 p. m.

After recess—2 P. M.

FREDERIC P. STEARNS, a witness called on behalf of the Sanitary District, was first duly sworn by the Commissioner, and testified as follows:

Direct Examination by Mr. Adcock.

Q. What is your full name?
A. Frederic P. Stearns.
Q. Where do you reside?
A. Boston, Massachusetts.
Q. Where is your place of business?
A. In Boston.
Q. What business are you in?
A. Civil engineering, chiefly with reference to hydraulic and sanitary work.
Q. You do consulting engineering work?
A. I do.
Q. Will you state your early training, experience, qualifications, official positions, if any you have held, positions with private concerns or corporations, and the duties which you were called upon to perform in connection with any and all the positions which you have filled?
A. I began engineering work in 1869, 44 years ago. I had a high school education; did not attend a technical school or college, but pursued the studies in mathematics which are taught in such schools, to a considerable extent.

From 1872 to 1880, I was engaged upon the preliminary work, the construction, and in the last years in the operation of a new system of water supply for Boston. In the construction, I was in charge of a division of the work. Incidental to this work, I had occasion as early as 1874 to measure the flow of the Sudbury River, using a current meter; and to do other hydraulic work. It was during the construction of these works that in collaboration with Mr. Fteley, I made several series of hydraulic experiments upon the flow of water over weirs, upon the flow of water through channels and pipes, and upon the current meter; these experiments being made for the purpose of deducing hydraulic

laws. The results of such experiments were published in the Transactions of the American Society of Civil Engineers, one of the papers receiving a Norman Medal for that year.

From 1880 to 1886, I was connected with the construction, and in the last years with the operation of the Boston Main Drainage Works, which is a main system of sewerage and sewage disposal for the City of Boston.

From 1886 until 1895, I was the chief engineer of the Massachusetts State Board of Health, being employed at first in connection with a legislative act which was entitled: "An Act to protect the purity of inland waters." It involved the consideration of the discharge of sewage into streams, the care and control of streams used for water supply, and the study of the condition of polluted rivers. A provision of the act required that all proposed systems of water supply in the state should first be submitted to the State Board of Health, before legislative action was taken regarding them.

Besides the work of the State Board of Health, of the character which I have mentioned, the legislature required the Board to devise a system of sewerage for the suburban cities, and parts of the City of Boston. And this system of sewage disposal, which was estimated to cost about six million dollars, was devised while I was Chief Engineer of the Board of Health.

Another legislative act required the Board to make an investigation for a water supply for Boston and its surrounding towns and cities, known as the Metropolitan Water District. This investigation was made, and the plan devised, under my direction, the estimated cost of the works being $25,000,000. From 1895 to 1907, I was Chief Engineer of the Metropolitan Water Board and its successor, the Metropolitan Water & Sewerage Board.

While holding this position, I had charge of the construction and operation of the Metropolitan Water Works, and was consulted in some matters relating to the sewerage works of the Metropolitan District, which were under the charge of the Metropolitan Water & Sewerage Board.

That is the end of my regular engagements as a Chief Engineer of a board. I resigned in 1907, so as to have time for consulting work. Apart from my regular occupation as chief engineer of these various works, I have been consulted in many cases. The first important engagement was in 1888 and 1889, when I was a member of a board of sanitary engineers, to report upon the sewerage of the District of Colum-

bia. This board advised a plan, which has since been carried out.

In 1892 I was one of the consulting engineers of the First Rapid Transit Commission of Boston. From September, 1903, for about five or six years, I was consulting engineer to the Charles River Basin Commission of Boston, which built a dam with a lock for navigation across a tidal estuary. This involved sanitary questions as to the pollution of the water, as the dam created a tidal basin into a fresh water basin.

From August, 1905, to date, I have been one of the consulting engineers of the Board of Water Supply of the City of New York. This is a work estimated to cost $162,000,000. I have not been actively engaged upon this work for the last two years or three years.

From August, 1905, to January, 1906, I was a member of the International Board of Consulting Engineers for the Panama Canal, to consider and report upon the plans for a canal across the Isthmus of Panama; and was one of the minority of five, whose plans were finally adopted.

From September, 1905, to June, 1906, I was a member of a Board of Advisory Engineers to the Sewage Commission of the City of Baltimore, to investigate and report upon a system of sewage disposal for that city.

In November and December, 1906, I was a member of a Board of Consulting Engineers to examine and report upon a proposed project for supplying water to the City of Los Angeles, California, from the Owens Valley. This project includes an aqueduct upwards of 200 miles in length.

In March and April, 1907, and again in January and February, 1909, I was a member of a Board of Consulting Engineers to visit the Isthmus of Panama and report upon certain questions for the Government.

From October, 1911, to January, 1912, I was engaged a part of the time on a study of the sewerage problem at Pittsburgh, Pa. Other engagements have included the valuation of the water supply of San Francisco; valuation of the water supply of Denver; valuation of the water supply of Oakland, California, which gave me an opportunity to become acquainted with the conditions in the arid sections of the country, including questions of rainfall and evaporation.

I have been connected within a year or two, with a hydro-electric project in Mexico, which also led to a study of questions of rainfall, run-off and evaporation. I have been connected with other hydro-electric projects in West Virginia,

in Pennsylvania not so very far south of Lake Erie; also with the construction of two large dams in Pennsylvania at Johnstown. And in the winter of 1913, I made a study of run-off and rainfall in Wisconsin.

I am still consulting engineer to the Metropolitan Water and Sewerage Board.

As to positions with engineering societies, I was president of the Boston Society of Civil Engineers in 1891, and of the American Society of Civil Engineers in 1906; and am an honorary member of the New England Water Works Association.

In June, 1905, I received the honorary degree of Master of Arts from Harvard University; and of Doctor of Science from the University of Pennsylvania in October, 1906.

Q. You commenced to practice your profession in 1874, was it?

A. In 1869.

Q. Have you been engaged continuously since that time in the practice of civil engineering?

A. I have.

Q. Has your practice brought you in contact with the questions of the measurements of discharges of rivers, and the use of instruments to measure such discharges?

A. It has, in the measurement of small rivers and of aqueducts, not of large rivers.

Q. Has your practice brought you in contact with question involving the effect upon lake levels of the enlargement of discharge or change of channels of an outlet?

A. My hydraulic studies have given me information in that matter, and I have this year made studies of the changes of lake levels.

Mr. Wilkerson: That is in connection with this case?

A. Yes.

Mr. Adcock: Q Have you made any study of the hydraulics, hydrography and hydrology of the Great Lakes, in connection with this case, or at any other time?

A. I have.

Q. Mr. Stearns, have you in your practice had any experience in the use of rainfall data as furnished by the United States Weather Bureau?

A. I have.

Q. Will you state what your experience has been?

A. The data has been satisfactory, when there have been a sufficient number of stations, so that one could take an average. I have found, at times, that a single station was

in error, referring particularly to the Boston station, for a number of years.

Q. Is there any data relating to the amount of rainfall derived from any other sources than the Weather Bureau?

A. Yes, it is customary in the case of extensive water works, and generally in the case of the smaller water works in the East, to have rain gages maintained by the Water Departments as a basis and they use those rain gages, which they are familiar with, rather than the Weather Bureau records.

Q. Is that because of the location of those gages with reference to a particular area, that which they wish to get the record of?

A. Yes, generally. For instance, on the Metropolitan Water Works of Boston, there are four gages located on the Wachusett drainage area, and four others located upon the Sudbury drainage area; the idea being in placing the gages to get a fair average of the amount of rainfall upon the drainage area, so that it can be compared with the measurements of the flow of the streams, and thereby deduce the relation of the flow of the streams to the rainfall.

Q. Have you made any investigation with reference to the evaporation, or the amount of evaporation at various temperatures; or are you familiar with investigations that have been made?

A. I am.

Q. And familiar with the results that have been obtained?

A. Yes.

Q. Will you explain the investigations that have been made, and your familiarity with such investigations, and the results accomplished?

A. The most elaborate measurements and tests for evaporation in the United States, and perhaps anywhere, have been made by Mr. Desmond Fitzgerald, who was for years in charge of portions of the Boston Water Works, and afterwards became a member of the staff of the Metropolitan Water Board, of which I was chief engineer. I was also on the Boston Water Works for a part of the time that Mr. Fitzgerald was engaged upon this work.

He made a very elaborate study of evaporation experiments, which are given in detail in a paper published in the Transactions of the American Society of Civil Engineers. I have examined the apparatus which he used, and knew of the results which he was obtaining from time to time; and have made a study of the results as published in that paper.

He not only used the experiments which he made himself, but other measurements that were made in some preceding years under the direction of the city engineer of Boston, and directly by Mr. Dexter Brackett. These experiments were made at what is known as the Beacon Hill Reservoir of the Boston Water Works. It was a reservoir supported upon arches, that had been thrown out of use so that no water was drawn from it or run into it; the only supply that it received being from the rainfall. And in that case, as in all other evaporation experiments, the rainfall is allowed for in such a way as to get the effect of evaporation.

Q. Was there any measurement of the rainfall?

A. Yes, the rainfall is measured in rain gages nearby the evaporating pans; but it also is deduced, to some extent, from the records of the rise of the water in the evaporating pans or tanks, as well.

The most accurate experiments made by Mr. Fitzgerald were with a tank made of copper, so that it would not leak, 10 feet in diameter and 10 feet high, which was suspended in the middle of Chestnut Hill Reservoir, from a very large raft; the raft being made large so that the waves could not possibly spatter in to the water in the tank, and therefore affect the accuracy of the observations. He had a recording gage that multiplied the effect of evaporation. It recorded it on a larger scale than the actual evaporation upon a diagram which was revolved by clock work, so that he could trace the evaporations from day to day; and also, of course, he took accurate measurements, with gages to determine precisely the amount of evaporation.

To go a little further, he collected his information from this tank and from the work done at the Beacon Hill Reservoir, and determined the evaporation for ten years. This has shown one feature, namely, that evaporation from water surfaces does not vary very much from year to year, even if the rainfall varies, but is fairly constant; so that in applying the results obtained by him to other places, one can do it with a fair assurance that there will not be any very wide change in the evaporation from year to year at a given place. The range in ten years was from 34.05 inches to 43.63 inches.

The comparisons between rainfall and evaporation for these ten years, in detail, are as follows:

Years	Rainfall.	Evaporation.
1876	49.56	39.06
1877	44.02	35.97
1878	57.93	37.76
1879	41.42	40.07
1880	38.18	40.47
1885	43.55	43.63
1886	46.06	40.80
1887	42.70	41.51
1888	57.46	38.60
1889	49.95	34.05
Average	47.08	39.20

I have had occasion to look into the question of evaporation in other places; that is, evaporation from water surface, in other places, especially with reference to determining the probable evaporation from a reservoir in the northern part of Mexico; and recently with reference to determining the evaporation from Lake Winnebago in Wisconsin. In connection with that, I obtained certain experiments upon evaporation, or measurements of evaporation, made by the United States Engineer Officers.

Q. Were you in touch with the experiments made at the place you have just mentioned, from time to time; that is, in Boston?

A. I was.

Q. Do you know anything about the accuracy or precision that was used in the making of those experiments?

A. I do. I saw the apparatus. I knew the man who conducted the experiments; and I know they were made with the greatest care.

Q. Among engineers, how are those experiments considered, with reference to accuracy?

A. I think they are considered as the best experiments for that section of the country, and as far as the care with which they were taken and the accuracy, as good as any—better than any in the United States.

Q. Will you describe a little more in detail how the experiments were made, the character of the instruments, etc., the time of reading and the time of taking?

A. I don't recall the time of taking the observations, as they were not under my direction. I merely visited the place on a few occasions, to see the apparatus and to have it explained to me. And I remember, as I have already described, this very delicate apparatus that was made by

an instrument maker, by which they could obtain a graphical record on an automatic diagram of the evaporation. But that was not the method by which they obtained the monthly and yearly evaporation. That work was done with the use of delicate gages that would register the height of the water to a thousandth of a foot, or even more closely.

I remember seeing one of these gages set upon certain metal points, a measurement being taken down to the surface of the water with that degree of accuracy. And those I know were done from day to day continuously throughout the season, so as to record all of the evaporation.

And as already stated, due allowance was made for the effect of rainfall, not only by the rise which occurred in the tank from which the evaporation was being measured, but also by rain gages located, I think, on the roof that held the tank. The object of the tank being made of copper, with only sufficient wood to support it thoroughly, was to have it maintain the temperature of the reservoir water so that it would represent that temperature, as temperature is a very important item in the amount of evaporation.

Q. Will you explain how temperature or other conditions affect the amount of evaporation?

A. The temperature practically is a very important item, the most important item in producing evaporation. We know water evaporates very rapidly when it is heated. The other governing features, or the principal governing features, in addition to the temperature, is the relative humidity of the air; that is the amount of moisture contained in the air. When air is saturated with all of the moisture it will hold, it reaches what is known as the dew point; that is the condition under which dew is deposited on the ground. And then there is no evaporation, unless the water is warmer than the air. At other times, the air contains a percentage of the amount of water required to saturate it, and that is known as the relative humidity. That is an important factor.

Wind is also a factor of importance, because the evaporation of water is governed by the relative humidity of the layer of air directly in contact with the water, perhaps only 1/8 of an inch thick, and that may have a greater humidity than the air higher up. If there is a good strong wind, it very quickly removes the layer of humid air next the water, and in that way facilitates evaporation. So that there are the elements: temperature of water, relative humidity and wind, as aiding in the removing of this damp layer.

Q. Does the temperature of the water depend somewhat on the depth of the reservoir?

A. To a very limited extent, in reservoirs of the size with which I am acquainted, for the reason that in the summer, the upper layers of the reservoir become warm and the lower layers remain cold, so that the amount of water to be warmed by the air is only a moderate depth from the surface.

Q. How large is this Chestnut Hill Reservoir which you mention?

A. I don't recall its exact size, but I should say less than a hundred acres—not a great deal less.

Q. And where was that located with reference to Boston?

A. It is five miles west of the center of Boston.

Q. How far from the coast?

A. About eight or ten miles from the general line of the coast; less than five miles from the inner parts of the harbor.

Q. Have you made any study or investigations, or have you been familiar with investigations made, and results reached, with reference to the run-off of streams?

A. I have.

Q. Just state what investigations you are familiar with, and what has been under your supervision or observation?

A. During a large part of my professional career, I have have had to consider closely, or have considered closely the run-off of streams in comparison with the rainfall.

I first began to measure the flow of a stream with reference to determining the ratio in 1874. In 1878 to 1880, I had occasion to compile such information. From 1886 to 1895, when I was chief engineer of the State Board of Health, I was continually using the information as to the relation between the rainfall and the run-off, as represented by the flow streams, and every year, in the reports of the State Board of Health, had occasion to incorporate such tables.

Also in making investigations for the Metropolitan Water Supply, as well, I determined the quantity which could be depended upon from a new source, on the basis of the relation of the run-off to the rainfall. Since I was chief engineer of the Metropolitan Water Works, up to about 1906 or 1907, I inaugurated the gaging of the streams represented by the new supply for use of the Metropolitan district, and had rain gages installed, and have kept those records.

I have also had occasion to use this method of determining the quantity of water which could be expected in storage

reservoirs, in other places, in connection with my consulting work.

Q. From these experiments, do you find any relation between the run-off and rainfall?

A. There is a fairly definite relation, when one takes an average of a series of years. It is much more definite than one might expect. As an instance of this, I will call attention to the amount of water in a series of years, which has run off from different drainage areas along the Atlantic coast, giving the percentage of the rainfall.

The Wachusett drainage area has an area of 118 square miles of land, that is partly wooded and partly cultivated land; and the run-off in 16 years has averaged 49.8 per cent. of the rainfall.

From the Sudbury drainage area, an area of 75 square miles, the run-off in 38 years has averaged 47 per cent. of the rainfall.

Upon the Croton drainage area, of nearly 400 square miles (this is one of the sources of supply for New York), the run-off in thirty-two years has averaged 47.10 per cent. of the rainfall.

There were three streams near Philadelphia that were gaged with reference to a probable water supply for that city, for 14 years. I do not recall the sizes of the drainage areas, but they were of several hundred square miles; that is, the drainage areas sufficient to supply the city of Philadelphia. And from one, the Perkiomen, the run-off was 49.2 of the rainfall; from another, the Neshaminy, 48.5 per cent. of the rainfall; and from another, the Tohickon, 57.6 per cent. of the rainfall.

Here are six different streams, with different conditions, and yet the variation has not been very much, and in many cases the percentages agree closely.

Q. How was the amount of run-off there compared with the rainfall determined, in those instances that you have mentioned?

A. As a general statement, it is made by measuring the water in various ways; and where the water is discharged from an aqueduct, it generally is measured in the aqueduct for that portion. Some portion flows over the dams, and that is measured by some formula for the flow over weirs.

Different methods are adopted in different cases, but with an idea of obtaining correct results, and such results are obtained where special appliances are used to get good results.

Especial care has been taken upon the Wachusett and

Sudbury watersheds, and I believe the Croton results are such as are trustworthy.

Q. Can you describe the methods used, for instance, for the Croton drainage, or the Wachusett, or both?

A. I can for the Wachusett drainage area. At first the stream was gaged, when there was no dam, no reservoir upon it; that is none built by the Metropolitan Water Board. At that time there was a recording gage at the side of a stream to show the height of the water, and very frequent current meter measurements were made, both winter and summer, so that by the use of the current meter measurements, in connection with the height of the stream, the quantity was deduced accurately.

Q. Were there any measurements of the rainfall taken at the same time?

A. Yes, continuously. The Metropolitan Water Board built a dam upon this stream, and an aqueduct to lead the water towards Boston. After the completion of the aqueduct, that was calibrated by means of current meter measurements, so that the water running through the aqueduct could be determined on the basis of a recording gage at the head of the aqueduct; but this was checked frequently by current meter measurements, because even in a masonry aqueduct, a little coating of fibrous material gathers on the side, a coating of slimy water which does affect the quantity flowing; and therefore, current meter measurements were taken frequently to check the change of the flowing capacity of the aqueduct.

I should say, in addition to this method, that a weir was placed at the lower end of this aqueduct, with a self-recording gage; and that was used also as a check upon the flow of water through the aqueduct.

More recently, a hydro-electric equipment has been placed at the base of the dam in the gate house so that the water before going through the aqueduct passes through turbines, and as the operation of the turbines would cause irregular discharges of water, so that the record could not well be kept by means of gage heights, and it also became necessary to remove the weir at the lower end of the aqueduct to give capacity, Venturi meters were installed, and the quantity is now gaged by means of Venturi meters, checked by current meter measurements in the aqueduct.

Q. Just describe the Venturi meter?

A. The Venturi meter is an appliance that is now used quite extensively. It is placed on the line of a pipe and

consists, in its ordinary form, of two cones; one which reduces the diameter of the pipe, we will say, to one-half or two-thirds of its size; and by means of gages connected with the pipe on the up-stream side of this tapering portion, and another pipe at the contracted section, which is known as the throat, it is possible, taking advantage of certain hydraulic laws, to record the quantity of water passing the meter.

The scientific demonstration is somewhat involved, and I think will not add any information.

The second cone is a long tapering cone that is enlarging as the water passes through it; and it helps to prevent the narrow throat from being a serious obstruction in the pipe to the flow of water.

The Venturi meters at the Wachusett dam are of a somewhat different pattern, created for that special case, but working upon the same principle and giving the same results.

In addition to the measurement of the water which goes through the aqueduct, it is necessary to measure the water which flows over the crest of the dam; but that represents a very small proportion of the water in this particular case, as the water has run over only a few days in the many years that it has been in existence.

Another factor is the quantity of water stored in the reservoir. If at the beginning of one year the water is low, and at the end of the year it is high, an account is taken of the quantity of water stored between the high and low water levels of that year, in determining the quantity for the year. That is, every precaution is taken to get an accurate measurement.

Q. Where are the records of these experiments kept, Mr. Stearns?

A. The results of the measurements are kept by the local superintendents at the different places, and sent in to the office of the Metropolitan Water and Sewerage Board each month; and that is true also of the rainfall records.

Q. What is the Metropolitan Water and Sewerage Board; how is it organized, and what are its functions, just in a general way?

A. It was created by an act of the legislature, on account of the peculiar condition of Boston and the towns in its vicinity. Within ten miles of the center of Boston, there are 28 cities and towns; not one municipality, as there would be in some other places within the same distance, and the necissity of water supply and sewerage required that there be

joint action, somewhat like the action of the Sanitary District of Chicago.

In this case, the legislature appointed a board of three men, giving them very large powers to carry out these plans of water supply and sewerage; and to have control of the operation of the water supply and sewerage works.

Q. While these experiments in run-off of the Wachusett drainage area were being made, were you associated in any way with those experiments?

A. I was chief engineer of the work, and the returns were made to me, until I resigned from the board. I still have an office and see those records as they come in from time to time.

Q. Is there any difference in the evaporation on water surface as compared with land surfaces?

A. Yes.

Q. Will you explain just what the different processes are of evaporation under the two different conditions?

A. Except in the winter, when the lakes are frozen over, there is a very marked difference between the evaporation from land and water surfaces. The water surfaces are always available for evaporation, while the land may be dry at times. Hence, there is much less evaporation from the land than from the water. The records of run-off that are obtained are the measurements of the evaporation from land surfaces.

I have stated that in the case of the Wachusett drainage area 49.8 per cent., practically 50 per cent. of the rainfall has run off in the last 16 years. The other portion has practically all evaporated. A little of it has gone into plants, but very little stays in the plants. It is evaporated from their leaves, and otherwise.

Q. Have you had occasion in your practice to use the results of these experiments as to run-off and evaporation rainfall, etc.?

A. I have.

Q. In your practice, have you had occasion to consider the reliability of the experiments of the data of run-off, rainfall and evaporation?

A. I have to a very large extent in my work, in connection with this State Board of Health; and in investigating and determining upon various water supplies. That is the method that has been used to determine the quantity of water in nearly all cases.

And further than that, I have been for two years the chair-

main of a committee of the New England Water Works Association upon the yield of drainage areas. And in that capacity I have received from two places in Connecticut, one in Rhode Island, four or five in Massachusetts, one in Vermont, and some others that I don't recall as to their location, returns of the run-off from drainage areas in connection with the rainfall, and have had occasion to compare the results obtained in different places. And as a result I have been able to determine the relations between run-off and rainfall, and to ascertain how far, by deduction, the practical application of that method can be trusted.

Q. Have you made any study of the rainfall records of the United States Weather Bureau, with reference to Erie, Ontario, St. Clair, and Michigan-Huron?

A. I have not of the Weather Bureau records directly, but I have examined the rainfall records given in the report of the chief of engineers for 1903, which are said to be deduced from the United States Weather Bureau records; or deduced at least in part.

Q. How frequently were gages placed in those drainage areas, if you remember?

A. The only information I have is shown upon the map contained in the report of the chief of engineers for 1903, Appendix FFF following page 2856. This map shows the location of stations from which the United States Weather Bureau and the Canadian Meterological Service obtained their records.

Q. How are they indicated on that map?

A. The report at page 2859 states that the Weather Bureau stations are indicated by special marks. The other stations are volunteer stations. They are all shown by circles; some being circles filled in with black, and the others open circles. The black dots represent the regular stations, and the circular the volunteer stations.

Q. What period of years do the observations as to rainfall in these drainage areas of the lakes cover?

A. Sixteen years, from 1882 to 1898, are shown in this report. There is a supplementary table, Williams' Exhibit 31, which continues the records to the end of the year 1906.

Mr. Adcock: I understand this whole report of the chief of engineers, the appendix, is in evidence, Appendix FFF for the year 1903; identified and it being agreed that either party may use any portion they desire.

Q. From examination of the Appendix FFF, report of the chief of engineers for the year 1903, the map which you

have examined, and Williams' Exhibit 31, have you reached any conclusion with reference to the reliability or unreliability of the rainfall data shown?

A. It is apparently good data, much better probably in later years than in 1882 and 1883, because of the increased number of Weather Bureau stations.

Q. That is, as a matter of fact, the best available and most accurate data that there is in existence, isn't it, with reference to those particular areas?

A. So far as I know, it is. The statements in the report indicate that, with the data at hand, the mean rainfall over the drainage areas was determined as well as it could be. That is to say, proper deductions were made as to the rainfall upon the portions of the drainage areas where the rainfall stations were omitted.

Q. Now, have you considered the relation between the conditions, atmospheric and otherwise, at Erie, Ontario, and Huron-Michigan, with reference to the similar conditions at the places where observations of rainfall, evaporation, etc., have been made, that you have mentioned?

A. I have.

Q. What is the relation?

A. The temperature upon the drainage area of Lake Erie, as given in the report of the chief of engineers for 1903, Appendix FFF, page 289, for the years from 1882 to 1898, are in very close accord with the temperatures in eastern Massachusetts, the average for the year varying less than one degree, by a comparison which I made.

Q. That is one per cent., you mean?

A. No, one degree of temperature, and for the different months in the summer being very nearly the same in the two places.

In regard to the temperature elsewhere, as to its variation from Erie and St. Clair, I have been governed by the tables in this report of the Chief of Engineers of the temperature at Ontario and Huron.

I have also compared, from this same group of tables in the report of the Chief of Engineers, the relative humidity at the respective lakes, and the mean monthly velocity of the wind.

Q. How do those conditions, the wind and the humidity, compare with the conditions in Massachusetts and other places where the experiments were made?

A. I did not make the comparison between Massachusetts

and these lakes in regard to wind or humidity. I could do so, but I haven't any data here.

Q. Would that comparison be material in investigations as to storage and local supply of the lakes?

A It would not, as to the relative humidity of two lakes, nor of the relative wind on two lakes.

Q Would it be material in connection with the use of these experiments which you have mentioned?

A I don't think it would be material.

Q. I will draw your attention, Mr. Stearns to Appendix FFF, Report of Engineers 1903, page 2862, which shows the relation of wind, velocity, temperature and humidity between the St. Clair and Erie basins, and the Ontario basin. Will you state just what the comparison shows?

A. The mean velocity of the wind per hour from 1882 to 1898, for the St. Clair and Erie basins, is given as 10.4 miles; for the Ontario basin 10.6 miles. The temperature for the St. Clair and Erie basins, for the same period of 16 years, is for the St. Clair and Erie basins 48.01; for the Ontario basin 44.10 degrees Fahrenheit.

The humidity, that is, the percentage of saturation, for the same term of years, was, for the St. Clair and Erie basins, 73.6 per cent and for the Ontario basin 74.9 per cent.

It is to be noted that there is very little difference in the amount of wind; only a small difference in the amount of humidity, but that there is a difference of nearly four degrees Fahrenheit in the average temperature of the air.

Mr. Adcock: I now submit to the Commissioner certain series of Tables and ask that they be marked Stearns' Exhibit 1 Tables A to G; and they may be marked with the understanding that we will substitute blueprints, immediately.

Q. I show you these tables, Mr. Stearns, and ask you to state what they contain and how they were made up; what you had to do with their compilation?

A. I wished to check the discharge as measured at the St. Lawrence River, at the Niagara River and at the St. Clair River by determining the local supply and storage of each of the lakes; that is Lake Ontario and Lake St. Clair and Erie, taken collectively. If this could be done so as to obtain accurately the quantity of water which these lakes would derive from their local drainage areas, as well as the amount of water that they would gain or lose through the difference of rainfall and evaporation upon the lake surfaces, then there would be a check upon the discharges at the different rivers.

The difference in the discharges, as for instance at Niagara and at the St. Lawrence River, should be equal to the local supply and storage of Lake Ontario.

The Table marked "A" shows the local supply and storage of Lake Ontario for the years 1883 to 1906. The second column contains the rainfall. This was taken for the years 1883 to 1894 inclusive, from the report of the Chief of Engineers for 1903, Appendix FFF page 2879; and for the remainder of the years contained in the table, from the last page of Williams' Exhibit 31.

The third column contains the estimated evaporation from the surface of Lake Ontario.

I should say with reference to both the rainfall and the evaporation, that for each year the table covers the period from June to November inclusive, and not the whole year, as it was desired to omit any effect of ice.

The evaporation for this period has been determined for each year to be 21.8 inches; and I will give the basis upon which that quantity was arrived at.

The experiments of Mr. Fitzgerald upon evaporation, as above stated, gave an average evaporation annually of 39.2 inches. This was subdivided by the different months as follows:

January	1 inch
February	1 inch
March	1.8 inches
April	3.1 inches
May	4.5 inches
June	5.4 inches
July	5.9 inches
August	5.5 inches
September	4.2 inches
October	3.1 inches
November	2.2 inches
December	1.5 inches

This shows clearly the much larger evaporation in the summer months. In making the table referred to, I adopted as the yearly evaporation of Lake Ontario, the amount determined by the Piche evaporometer, as testified to by Mr. Williams, amounting to 30.6 inches annually. The evaporation at Lake Ontario would be less than in Massachusetts, on account of the colder weather; and I thought there might be reasons why it would be somewhat less than the evaporation in Mr. Fitzgerald's experiments, on other grounds, namely,

that the increased humidty, due to a large lake, might rather more than offset the greater effect of the wind upon such a lake, as compared with the effect of the wind upon a small reservoir.

It is not very material to the computations that the precise amount of evaporation should be determined; and I concluded to use the quantity given, as stated for the annual evaporation. This I divided, for the different months of the year, so as to conform to the variation from month to month in the Fitzgerald experiments. And as a result, I obtained 21.8 inches for the six months from June to November inclusive, which I have used in the table. I afterwards saw the results of the monthly evaporations by the evaporometer mentioned, and they coincided with this amount that I had otherwise determined within less than one inch.

The rainfall and evaporation being known, the effect of the lake surfaces is directly the difference between the two for a given period. That is to say, of the rain that falls on the surface of the lake, every particle of it becomes at once a part of the lake and of the water supply. The evaporation that takes place from the lake, that of course is immediate. If a half an inch is evaporated in a day, or a quarter of an inch, it is gone. And hence the difference between the two represents the gain or the loss from the lake surfaces.

The fourth column of the table represents this gain or loss due to evaporation, in inches, and as sometimes the rainfall is in excess, and at another time the evaporation is in excess, a plus or minus sign has been added before each quantity.

Q. What does the plus sign indicate?

A. The plus sign indicates that the evaporation is in excess of the rainfall, and the minus sign represents the rainfall in excess of the evaporation.

The fifth column is a mathematical deduction from the fourth column. It represents the number of cubic feet per second during the six months period, which corresponds to the number of inches of excess of evaporation or rainfall.

The plus and minus signs are applied in this column, in the same way as in the previous column.

The sixth column represents the run-off from the land into Lake Ontario, and this is determined by taking the area of the land as one factor, the amount of rainfall as another, and by the assumption that 21 per cent of the rainfall upon the land during those six months found its way into the lake, through streams, or by percolation. It is an assumption

based upon the experience with run-off in other places under similar conditions.

Q. What other places?

A. I have not the places at present here; that is as applied in this particular case. It is the result of my experience, where I have looked into the records of the run-off of other places, the Sudbury watershed, and others, and have applied them in other cases and it was my judgment that 21 per cent. of the rainfall during six months, under these conditions, would run off into Lake Ontario.

The only record that I have with me at present is one of 16 years' flow from the Sudbury River drainage area, during these months; and in that case, for the average of 16 years, the rainfall was 22.748, while the run-off was 4.855.

In this particular instance the run-off was 21.3 per cent. But I did not base it upon that alone, but rather upon my judgment that I had used elsewhere, and remembered. I could furnish, if necessary, a large amount of material bearing upon that point.

Q. Which will you do, if requested?

A. I will. The 7th column takes account of the storage in Lake Ontario. If during a six months' period, such as is included in this table, the lake either lowers or rises, it has its effect upon the relation between the discharge of water going into it, and the discharge going out. For instance, if one had a lake without any inflow or evaporation, and it were to lower during the six months, then more water would run out at the lower end than ran in at the upper end, by reason of the amount of water drawn from the lake; and this column is intended to provide a correction for the change in level.

That can be made perfectly accurate if the elevations of the lake at the beginning and end of that period are correct. And I think there can be no doubt they are sufficiently correct, so that no error is introduced by reason of column 7, in a six months' period.

Q. In making up column 7, then, you had to take into consideration the elevations of the lake, at the beginning and end of the period for each year, did you not?

A. Yes. And I should say that those were taken from the Report of the International Waterways Commission on the Regulation of Lake Erie in 1910, Table XXVII, beginning at page 141. The elevations taken were those on the first day of June and on the first day of December, as before, representing the period from June to November, inclusive.

Q. That is the beginning and end of a period?

A Yes. The summation of the quantities in column 5, 6 and 7, with due regard to the algebraic signs, gives the total local supply and storage, which is given in the final column, 8.

Q What do you mean by local supply and storage, as applied to the column referred to?

A. It means that it is the quantity of water which, if it were determined accurately, if subtracted from a discharge measurement below Lake Ontario, would give the correct discharge at Niagara. That is, it is the correct difference—it would be, if correct, the correct difference between the discharge at Niagara and at the St. Lawrence River.

Q. That column, then, represents the storage and local supply?

A. Yes, sir.

Q. Correctly, as you have deduced it from the other columns that you have referred to in the table, is that correct?

A. It does. And it is as correct as, in my judgment, it is practical to make it; and sufficiently correct to be used as a measure of the difference between the discharges of Niagara and at the St. Lawrence River.

Q. For the period of years which is indicated on that table?

A. Yes.

Q. Now, Mr. Stearns, directing your attention to the other tables in Stearns Exhibit 1, will you explain those, and also whatever reference Table 1 may have to the other tables.

A. Table B gives the local supply and storage for Lakes St. Clair and Erie, and is obtained in the same way as the last table, with two exceptions. The rainfall is taken from the same sources. The evaporation in this case for the six months is determined to be 24.4 inches, instead of the 21.8 inches determined for Lake Ontario. This is a proportional change made on account of larger evaporation at Lake Erie, as determined by the Piche evaporometer, as testified to by Mr. Williams, and is a proper proportion of a total evaporation of 35.6 inches annually, as determined by that instrument. It also is a reasonable difference from the evaporation found for Lake Ontario, because the average temperature of the air at Lake Erie and Lake St. Clair is 4 degrees warmer than the average temperature of the air at Ontario, as already stated.

Q. Have you taken into consideration the difference in the depths of Erie and Ontario, if there is any difference?

A. I have not.

Q. Did you or did you not consider that was material in determining the difference, the probable difference of evaporation of the two lakes?

A. It did not seem to me that it was material for the reason that the temperature of water, in cases where I have knowledge of such temperature, follows very closely the temperature of the air, for the portion of the year from April to August. After that date, it is generally higher than the temperature of the air.

I make this statement as the result of a great many studies of the temperatures of lakes, in which I have compiled the results and compared them with the temperature of air. I have not made any studies of so large a lake, and did not have available any material other than a diagram, which I found in the report of the Chief of Engineers for 1903, Appendix FFF, preceding page 2687. This diagram gives the temperature of the Detroit River at Fort Wayne, on several occasions in 1901 and 1902, in degrees Fahrenheit. The average temperature of the water for July was 67 degrees.

I have no records to show the mean temperature of the air for this particular month; but the average temperature of July for the years 1882 to 1898 was 71.1 degrees, as given in the report of the Chief of Engineers, Appendix FFF, 1903, page 2880, Table 16.

In August, the temperature of the water was 73 degrees, and the mean temperature of the air, from the table aforesaid, 68.6 degrees. In September, the temperature of the water 65 degrees; temperature of air 63.2 degrees; October, temperature of water, 54 degrees; temperature of air, 50.7 degrees.

These results indicate in a general way that the temperature of the Detroit River water is not very different from the temperature of the air; and I think that relation would hold fairly well in the different lakes.

Q. How about Lake Erie?

A. It would apply to Lake Erie as well as Lake Ontario. In smaller lakes, the water in the lower part of the lake does not become warmed; and I think that is true of the Great Lakes; that they do not overturn from the effects of the wind to the bottom, during the summer season, and consequently the water in the bottom of the lakes is not a factor in the temperature of the surface water.

Q. Have you taken into consideration the comparative humidity and the wind of the two lakes?

A. I have not, for the reason that there is practically no difference.

Q. As you have explained heretofore, in the reference to the Appendix FFF, Report of Chief of Engineers for 1903?

A. I have.

Q. Now, will you continue with the explanation of the tables of Stearns Exhibit 1?

A. The 4th and 5th columns, giving the excess of evaporation, correspond with the similar columns in Table "A," as already explained.

The 6th column contains the run-off into St. Clair and Erie in cubic feet per second. And this differs from the 6th column in Table A only in this: That the run-off in this case has been determined to be 20 per cent. of the rainfall, and not 21 per cent.

Q. How did you determine that percentage of run-off compared with rainfall?

A. On the same basis as I determined the percentage of run-off of Lake Ontario, by taking into account that the rainfall is slightly less on Lakes Erie and St. Clair than on Lake Ontario; and that the temperature, and consequently the evaporation, are somewhat greater.

Q. In that connection, were you referring to the areas of the lakes, or the drainage areas of the lakes?

A. I was taking the drainage basins as a whole. The temperatures and rainfall are given for the basins as a whole, including the lakes, as I understand it.

Q. That included the area of the lake surface?

A. It has a minute correction, and yet the tendency would be for the percentage of the run-off to be somewhat less, as I believe, on Lake Erie than on Lake Ontario, for the reason stated.

Column 7 which gives the storage in Lakes St. Clair and Erie, is similar to the same column in Table A; but in computing it, there has been taken into account the elevations at the beginning and end of the period, of both Lake Erie and Lake St. Clair, as given in the report of the International Waterways Commission on the Regulation of Lake Erie, for 1910, Table XXVI, beginning on page 131 for Lake Erie, and Table XXV, beginning on page 117, for Lake St. Clair.

The 8th column gives the total local supply and storage for Huron, Erie and St. Clair, and corresponds to column 8 of Table "A."

Adjourned to Wednesday, March 26, 1913, 10 A. M.

Wednesday, March 26, 1913; 10 A. M.

Parties met pursuant to adjournment.

Present same as before.

FREDERIC P. STEARNS resumed the stand and testified as follows:

The Witness: In Table C, the discharge of the Niagara river is deduced from the discharge of the St. Lawrence river by subtracting from the latter the total local supply and storage of Lake Ontario, as given in Table "A."

The principle involved is this: That if the outflow from a lake has been accurately determined, the amount of water flowing into that lake can be determined if the amount of water yielded by the intermediate drainage area is known, and due allowance has been made for the rise or fall of the water of the lake.

Column 1 of this table gives the year; column 2 the discharge of the St. Lawrence river for the six months from June to November, inclusive, as given in the Report of the International Waterways Commission on the Regulation of Lake Erie for 1910, Table XXVII, beginning on page 141, in cubic feet per second.

Column 3 is the total local supply and storage of Lake Ontario, as given in Column 8 of Table A.

Column 4 is the deduced Niagara discharge in cubic feet per second, obtained by subtracting the quantities in Column 3 from the quantities in Column 2.

Q. Just describe what is in Column 3, being the storage and local supply, is that right?

A. Yes, being the local supply and storage of Lake Ontario.

Column 5 is the discharge of the Niagara river, as determined by the International Waterways Commission, and given in Table XXVII aforesaid. The difference in the deduced discharge of the Niagara river, as given in Column 4, and the computed discharge of the Niagara river as given in Column 5, shows the error in the computed discharge, by this method of checking the results. The error in the computed discharge as given in Column 5 averages 16,390 cubic feet per second, when the years 1895 and 1896 are omitted; these two years being omitted because the results appeared

to be especially inconsistent, on account of the low stage of the lakes at that time.

The comparison in this table has been made with the Niagara discharge, as determined by the International Waterways Commission, as a matter of convenience in computation, afterward a comparison was made between the discharge as given in the tables of the International Waterways Commission, and the discharge as given in Williams Exhibit No. 34, Tables XI and XII.

Q. That being the complainant's equation?

A. These tables representing the discharge of the Niagara river by the complainant's equations for the Bridge Section, and for the Open Section, from 1900 to 1906 inclusive.

Table D differs from Table C only in the basis used for the discharge of the St. Lawrence river. In Table D, the discharge of the St. Lawrence has been computed by defendant's equation as given in Table XLIII-A of Williams Exhibit 34.

By this change in the basis of computation, the average error for the 24 years from 1883 to 1906, inclusive, excluding however the years 1895 and 1896 for the reasons before given, and the years 1904-05-06 on account of the effect of the Gut Dam, is 16,070 cubic feet per second, in the place of 16,390 cubic feet per second; and this comparison shows that the discharge of the Niagara river based upon the measurements made at that place, is too low by these quantities.

Table E is similar to the last two tables described, except that it starts with the discharge at Niagara, as computed by the International Waterways Commission, and as given in column 5 of Table C and Table D, and from that discharge deduces the St. Clair discharge. The deduced quantities are obtained, in the way before described, by subtracting the local supply and storage of Lakes St. Clair and Erie, as given in column 8 of Table B, from the Niagara discharge, and obtaining a deduced St. Clair discharge.

Q. That is by the method you are pursuing here?

A. Following exactly the same method described in reference to the former tables.

This deduced discharge is given in column 4; and in column 5 is the discharge of the St. Clair river, by the complainant's equation.

Column 6 shows the differences between the deduced discharge of the St. Clair river, as given in column 4, and the discharge by complainant's equation as given in column 5. It shows in general that the differences were much greater in

the earlier periods, say from 1883 to 1889, than in the later periods, but I have made no general deductions from this table by averaging, because the complainant's equation does not take into account the elevation of Lake St. Clair, which is an important factor; and that is taken into account by the defendant's equation which is used in the preparation of Table F, and should therefore make the results in Table F more accurate than the corresponding results in Table E.

Table F is similar to Table E, being changed only by the introduction in Column 5 of the St. Clair discharge by the defendant's equation, in place of the St. Clair discharge by the complainant's equation. The differences between the deduced discharge and the computed discharge of the St. Clair river are given in Column 6. It is not feasible in this case, as in the case of a comparison with the St. Lawrence discharge, to use the whole period to ascertain the error in the relation of the Niagara and St. Clair discharges, because there have been deepenings of the St. Clair and Detroit rivers, and improvements of channels, which makes any equation deduced from measurements in the years 1899 on inapplicable to the earlier years.

I have therefore taken for the comparison to ascertain the error in the Niagara discharge or the St. Clair discharge, the years from 1897 to 1906. The difference for that period is 20,700 cubic feet per second. If the St. Clair discharge is assumed to be correct, then the Niagara discharge as computed by the International Waterways Commission for these years, is 20,700 cubic feet per second too low, confirming quite closely the determination made by a comparison of the St. Lawrence and Niagara.

Q. In other words, on that table, you use as a basis the measurements made by the International Waterways Commission, is that correct?

A. At Niagara.

Q. On the Table F that you have just mentioned?

A. Table F.

Q. Which compares with the outflow shown by the defendant's equations?

A. Yes; and reached the conclusion that the Niagara discharges are too low rather than that the St. Clair discharges are too high, because that view is confirmed by the fact that the Niagara discharges are also shown to be too low by the comparison with the St. Lawrence measurements, and to nearly the same extent; that is, the difference being from an

average of 16,230 cubic feet, when the computation is based on the St. Lawrence discharges, and 20,700 feet, when the computation is based on the St. Clair discharges, the average of the two results indicating that the Niagara discharges are 18,465 cubic feet per second too low, or, say in round numbers, 18,000 cubic feet per second.

The average difference between the deduced St. Clair discharge, and the discharge obtained by the defendant's equation for the years 1883 to 1888 inclusive, was 55,200 cubic feet per second. This is a quantity that was in excess of any probable error during those years, in the estimated discharge at Niagara, and consequently must be ascribed to the fact that the channels of the St. Clair and Detroit rivers were smaller in those early years, and that the discharge as computed by the defendant's equation is not correct, for the reason that it was deduced on large channels, and cannot be applied to smaller ones.

I will not refer to the extent of enlargement of channel indicated in this case, because the column is based upon the incorrect Niagara discharges; and the extent to which they were incorrect in those years is not represented by the average error in the discharges for a long period of years; it was more in those years when the water was higher than in other years, for the reason that there is another table G, which makes a comparison that eliminates the effect of the errors of the Niagara discharge.

This is a table in which the discharge of the St. Clair river is deduced directly from the discharge of the St. Lawrence river, in the same manner as has been described for the other cases. In this table, the years have been grouped into three periods, the first covering the years 1883 to 1888; the second, the years from 1889 to 1891; and the third, the years from 1892 to 1903 inclusive. The remaining three years, which have appeared in the other tables were omitted, so as to eliminate the effect of the Gut Dam.

Column 2 of this table contains the average discharge of the St. Lawrence river from the month of June to November, inclusive, as determined by the defendant's equation already referred to. From the discharge at the St. Lawrence, as given in column 2, there has been deducted both the local supply and storage of Lake Ontario, as given in the 8th column of Table 1, and the local supply and storage of Lakes Erie and St. Clair, as given in column 8 of Table B; producing in the

5th column the deduced St. Clair discharge for the three periods.

In the sixth column of the table is given the discharge of the St. Clair river for the three periods, as obtained by the defendant's equation already referred to.

The 7th column gives the difference between the deduced discharge, and the discharge as computed by the equation. For the first period, from 1883 to 1888, this difference is 27,900 cubic feet per second. For the second period, 1889 to 1891, the difference is 14,400 cubic feet per second; and for the third period, from 1892 to 1903, 10,100 cubic feet per second.

The quantity for the last period represents about 5 per cent. of the total discharge; and is the result of what may be called unavoidable inaccuracies in the determination of the discharge of the St. Clair and the St. Lawrence rivers, and of the local supply to Lakes Ontario, Erie and St. Clair. Such hydraulic measurements and determinations do not permit of mathematical accuracy, and a variation of only 5 per cent. in results obtained by the methods followed, I regard as a good check upon the general methods.

Q. Will you explain what you mean by the use of the expression "unavoidable inaccuracies of measurements", to what measurements and methods you refer?

A. I refer to all of the determinations included in the computation; the measurements of the flow of rivers by current meters in connection with lake stages, the determination of the run-off into the lakes, the amount of evaporation and rainfall, and the effects of storage, although the effects of storage are subject to very small error. But it is not to be expected that in a comparison of this kind the results would come nearer than 5 per cent. They are sufficient, however, to detect the greater errors with certainty, such as the inaccuracies of the measurements of the Niagara river, which is a very much larger quantity.

Q. Can you, by this method, detect the enlargement, the material enlargement of a channel, where it was enlarged so that it would flow 24 or 25,000 cubic feet per second more, in channels the size of the St. Clair river?

A. Yes. The uncertainty would relate only to the small percentage which I have referred to. The difference between the deduced and computed discharge in the first period, from 1883 to 1888, was 27,900 cubic feet per second. If it is assumed that the St. Lawrence discharge is absolutely correct, and that the local supplies and storage of the three

lakes are also exactly correct, then this would show that the channels had been enlarged so that they will carry 27,900 cubic feet per second more than they would have in the years 1883 to 1888 inclusive.

If, however, we make the assumption that the difference of 10,100 cubic feet per second between the deduced and computed discharge in the last period, from 1892 to 1903 inclusive, means that the inaccuracy is in the measurement of the St. Lawrence river, and in the determination of the local supplies and storage of Lakes Ontario, Erie and St. Clair, which is also an assumption that the discharge of the St. Clair river for this period, as computed by the defendant's equation is correct, then there should be deducted from the 27,900, 10,100, leaving 17,800 cubic feet per second as the effect of the deepening of the channel.

As we cannot tell which of these two results is correct, I should say that the deepening of the channels may be represented by any quantity between 17,800 and 27,900 cubic feet per second. I do not think the determination could be made to say just what the amount is between those limits.

The difference between the deduced and computed discharge of the St. Clair river, during the second period, was 14,400 cubic feet per second, which is intermediate between the results of the first and the last periods, and indicates that there has been some deepening of the channel since 1889 to 1891.

Q. Now, referring to the deductions on Table G, the last line, the period from 1892 to 1903 inclusive, if there could be eliminated all the possible inaccuracies of the measurements of the discharge of the St. Lawrence river, and all the possible inaccuracies in the method which you have followed in determining local supply and storage, what would the result in the last column be, column 7?

A. It would show that the discharge of the St. Clair river, as computed and given in column 6, was 10,100 cubic feet per second too large.

Q. Now, Mr. Stearns, how closely is it necessary, in dealing with such large quantities of water as we have to deal with here, to determine the percentage of run-off and the amount of evaporation, in order to obtain reasonably accurate results? Will you just explain how an error in that regard would affect the ultimate result?

A. In determining the amount of water which runs off into a lake, as for instance Lake Ontario, one is dealing with quantities which are small in comparison with the quantity of

water running in the main rivers, the Niagara and the St. Lawrence. For instance, the run-off into Lake Ontario, as determined and given in column 6 Table A, averages approximately 16,000 cubic feet per second, while the discharge of the St. Lawrence and Niagara rivers is, by inspection of Table C, about 230,000 cubic feet per second. That is, the run-off into the lake is about 7 per cent. of the whole quantity.

Q. That is, from the drainage area, the local supply?

A. From the drainage area, the local supply. Consequently an error of 14 per cent. in determining the run-off from the drainage area into the lake would represent only one per cent. of the whole quantity, so that an error in the determination is greatly minimized when it becomes a part of the flow of the whole river. In a similar way, an error in the computed amount of evaporation of 4 inches, which in the case of Lake Ontario amounts to about 13 per cent., would affect the results as applied to the discharge of the main rivers only to the extent of about 1½ per cent.

As already stated, the storage factor, which is a large part, in the case of Ontario, of the deductions made to obtain the amount of inflow, can be determined accurately for periods of six months, or longer.

Q. Is the run-off from the drainage area per cubic feet per second one of the items of local supply?

A. It is.

Q. What are the other items of local supply, if any?

A. There is one other item, which is the yield of the lake surfaces, and it is represented by the difference in the rainfall upon the surface of the lakes, the evaporation from the surface of the lakes. These two quite nearly balance one another, so it is a small item.

Q. How do you determine the amount of water stored or drawn from a lake, in cubic feet per second, for a certain period?

A. The height of the lake at the beginning and end of the period is ascertained and the difference between the two heights is taken. If this is in feet, it is multiplied by the area of the lake in square feet, and in this way the number of cubic feet of water added to or drawn from storage in the lake is ascertained. This result is divided by the number of seconds in the period, and in this way the number of cubic feet per second is ascertained.

Q. Now, having the outflow of a lake for a certain period, the cubic feet per second, the run-off from the drainage area

of the lake per cubic feet per second, and the difference between the precipitation and evaporation of lake surfaces, in cubic feet per second, and the amount of water stored or drawn from the lake in cubic feet per second for a certain period, how do you determine then from those items, if at all, the inflow from another drainage area?

A. That can be explained the most clearly by taking each one of these elements separately.

The amount of water running into a lake from its drainage area evidently adds to the quantity flowing out its outlet. Hence to get the quantity coming in at the inlet, it is necessary to subtract the water which has been contributed to the lake from its drainage area through the streams that enter the latter. That is, they furnish a part of the water at the outlet, and hence the quantity of water at the inlet is smaller by the amount so supplied to the lake.

In regard to the precipitation upon, and evaporation from the surface of the lake, this may be either an additional quantity supplied to the lake, when the rainfall is greater, or it may cause a loss of the part of the water flowing into the lake, if the evaporation is greater than the rainfall. In that case it furnishes an outlet for a part of the water. Hence when the rainfall is greater than the evaporation, the resulting quantity should be subtracted from the outflow to obtain the inflow, and when the evaporation is in excess of the rainfall, then the reverse is true.

The third item, which is the number of cubic feet per second due to the amount of water stored in, or drawn from the lake, from the beginning to the end of the period, is, first, in case the lake has lowered during the period, the quantity represented by the lowering should be subtracted because a part of the water measured at the outlet is derived from the lowering of the water in the lake. While if the lake rises during the period, the quantity of water represented by the rise should be added to the outflow from the lake, in order to obtain the inflow.

Q. Have you made any other computations, Mr. Stearns, or comparisons between the discharge measurements, records of discharge measurements of the St. Clair, Niagara and St. Lawrence rivers?

A. I have.

Q. Will you state the facts which you have used in making your computations and the basis of your computations and

the conclusions that you may have reached from such calculations?

A. These computations were made before the detailed computations already testified to. They were based upon information furnished by Mr. G. S. Williams, which has since been included in the testimony in this case.

Q. Is that testimony that you have heard?

A. I have heard it, yes. I first made a comparison between the discharge of the St. Clair and St. Lawrence Rivers for the years 1900 to 1904 inclusive. The mean discharge of the St. Lawrence river for this period, as determined by the complainant's equation, Table XLIII, Williams Exhibit 34, was 240,820 cubic feet per second. The mean discharge of the St. Clair river, by complainant's equation given in Williams Exhibit 34, Table XX, was 188,787, cubic feet per second; a difference of 52,033 cubic feet per second.

During the five years, Lake Ontario raised 1.45 feet, and Lakes Erie and St. Clair, an average of 0.445 feet, so that some water was stored in these lakes which, had it not been stored, would have increased the St. Lawrence discharge, and consequently the difference between this discharge at St. Clair and St. Lawrence. This amounts to an average, during the five years, of 826 cubic feet per second, due to the storage in Lakes St. Clair and Erie, and 1855 cubic feet per second, due to the storage in Lake Ontario, a total of 2,681 cubic feet.

Q. Now the storage that you refer to there is the amount that was drawn from or added to those lakes?

A. It is.

Q. According to the difference in elevations in the period?

A. It is.

Q. In this case it was added to?

A. During the same five years, the average annual rainfall on Lakes St. Clair and Erie amounted to 30.92 inches and on Lake Ontario, to 33.42 inches. The evaporation experiments with the Piche evaporometer, already referred to, indicate an annual evaporation in the vicinity of Lake Erie of 35.60 inches, and near Lake Ontario 30.65 inches.

Judging from evaporation experiments elsewhere—and I am referring to those made by Mr. Fitzgerald—it seems reasonable to accept these quantities of evaporation as applicable to the lakes, and on this basis there was, therefore, an average annual excess of evaporation over rainfall, on Lake St. Clair and Erie of 4.68 inches, and an excess of rainfall over evaporation from Lake Ontario, amounting to 2.77 inches.

The excess of evaporation from Lakes St. Clair and Erie is equivalent to 3,610 cubic feet per second, during the five-year period, and the excess of rainfall upon Lake Ontario is equivalent to 1,480 cubic feet per second for the same period, making the net excess of evaporation equivalent to 2,130 cubic feet per second.

This amount is to be added to the difference in discharge already stated, as well as the 2,681 cubic feet per second attributable to storage in the lakes, already stated, making a total addition of 4,811 cubic feet per second.

The corrected difference between the discharges at the St. Clair river and the St. Lawrence river is, therefore, 52,033 plus 4,811, making a total of 56,844. The average annual rainfall, during the five years, upon the drainage areas of the lakes, exclusive of the lakes themselves, was, upon the 5,691 square miles of drainage area of Lake St. Clair, 31.602 inches; upon the 24,605 square miles of drainage area of Lake Erie, 35.046 inches; upon the 25,737 square miles of drainage area of Lake Ontario, 36.254 inches.

If all of the rainfall upon these drainage areas had run off into the lakes, the discharge for the five years would have averaged as follows:

St. Clair drainage area	13,250	cubic feet per second
Erie drainage area	63,000	do
Ontario drainage area	68,800	do
make a total of	145,650	cubic feet per second.

The difference in the discharge of the St. Clair and St. Lawrence rivers, corrected as above stated, for storage, and the difference between rainfall and evaporation upon the lake surfaces, was 56,844 cubic feet per second. Hence the run-off from the drainage areas, by the comparison, is 56,844 divided by 145,650, equal to 39 per cent. of the amount of rain falling upon the drainage areas, a figure which accords well with other experience.

A similar comparison made between the discharge of the St. Clair and Niagara rivers, covering the same period, from 1900 to 1904, inclusive, gave these results. The mean discharge of the Niagara river by the complainant's two equations, as given in Williams Exhibit 34, Tables XI and XII, was 196,739 cubic feet per second. The mean discharge of the St. Clair river, by the complainant's equations, as before stated, was 188,787 cubic feet per second; the difference being 7,952. Three corrections are needed to this difference: first, a correction for storage in Lakes St. Clair and Erie, as before

stated, 826 cubic feet per second; a correction for the excess of evaporation over rainfall of Lakes St. Clair and Erie, as before stated, 3,610 cubic feet per second; third, a correction for the amount discharged through the Welland and Erie canals, as stated in the report of the Chief of Engineers of the United States Army for 1904, Appendix EEE, page 4116, 2,300 cubic feet per second. All of these, amounting to 6,736 cubic feet per second, should be added to the difference between the discharges of the Niagara and St. Clair rivers—giving a total of 14,688 cubic feet per second, which represents this difference corrected for storage, yield of the lake surfaces, representing the difference between rainfall and evaporation, and the diversion through the Welland and Erie canals.

The difference also represents the amount of water derived from the drainage areas of the lakes. If all of the rainfall upon the drainage areas of the lakes, St. Clair and Erie, had run off into the lakes, the quantity of water would have averaged, for the five years, 13,250 cubic feet per second, plus 63,600 cubic feet per second, as before stated, making 76,850 cubic feet per second. Hence, the run-off from the drainage areas, during these five years, is by the comparison 14,688 divided by 76,850, equal to 19 per cent. of the rain which fell upon the drainage areas, a figure so far below the results of other experience as to be unreasonable.

Q. When you refer to drainage areas, do you include there the lake surfaces as well?

A. No, these are the drainage areas, exclusive of the lakes. A similar comparison was made of the discharge of the Niagara and the St. Lawrence rivers, for the same period as before, 1900 to 1904, inclusive. The mean discharge of the St. Lawrence river was, as before, 240,820 cubic feet per second.

Q. That is, by complainant's equation?

A. Yes. The mean discharge of the Niagara river by the complainant's two equations was, as before, 196,739 cubic feet per second, a difference of 44,081 cubic feet per second. Adding a correction for storage in Lake Ontario, as before, 1855 cubic feet per second, gives as the sum 45,936 cubic feet per second. Correcting for an excess of rainfall over evaporation at Lake Ontario, as before stated, there is a deduction of 1,480 cubic feet per second, and correcting for the amount of water discharged through the Welland and Erie canals, as before stated, a further deduction of 2,300 cubic feet per second, making a total deduction of 3,780 cubic feet per second, which,

subtracted from the 45,936 cubic feet per second leaves 42,156 cubic feet per second to represent the yield from the drainage area of Lake Ontario, exclusive of the area of the lake itself.

If all of the rainfall upon the drainage area of Lake Ontario had run off into the lake, the quantity of water would have averaged for the five years, 68,800 cubic feet per second. Hence the run-off from the drainage area, during these five years, is, by the comparison, 42,156 divided by 68,800, equal to 61 per cent. of the rain falling upon the drainage area; a percentage so large that it does not agree well with other experience, and is especially unreasonable when compared with the run-off of 19 per cent. from the drainage areas of Lakes St. Clair and Erie, during the same period.

It will be noted that the comparison between the St. Clair and St. Lawrence discharges gives reasonable results, while the two comparisons in which the Niagara discharge is involved, give unreasonable results; especially in view of the fact that the conditions at the two lakes are quite similar, and that they are not very far apart.

The discharge at Niagara will be computed from the discharge at the St. Clair and St. Lawrence stations, by making the corrections already described, and assuming that the yield from the drainage areas is 39 per cent. of the rainfall upon them, as deduced by the comparison between the discharges at St. Clair and St. Lawrence. Upon this basis, the discharge of Niagara, during the five-year period, amounts to 212,040 cubic feet per second, which is equal to 15,301 cubic feet per second or 7.8 per cent. more than the discharge as determined by the average of the complainant's two equations.

It will be noted that this result, obtained by using the full year for the five years mentioned is not far different from the result obtained by using the six months from June to November, when there certainly was no ice. I have noted that the discrepancy between the discharge of the St. Clair and Niagara rivers has been noted by others.

Q. What do you refer to, Mr. Stearns, when you say you had noted that this discrepancy has been noted by others?

A. In the Report of the Chief of Engineers for 1904, Appendix EEE, page 4125, this page being a part of the report of Thomas Russell, Assistant Engineer, this statement is made:

"The discharge of Detroit river for 11 years, 1893-1903, is on the average 193,854 cubic feet per second. The dis-

charge of Niagara river for the same time, is 197,328 cubic feet per second. The discharge of the Niagara river should be 30,100 cubic feet per second greater than the discharge of the Detroit river. It would require a very great, a totally inadmissible, evaporation from the lake to have the difference in discharges as small as the observations indicate."

The conclusions of Mr. Russell were based upon the records for the 11 years, 1893 to 1903, and therefore cover a different period from that used in the comparison before made, based upon the years 1900 to 1904.

Q. In determining the effect of a diversion from Lake Michigan-Huron, is it necessary to determine an increment for the St. Clair river?

A. Yes.

Q. Why is that necessary?

A. The increment, using the definition that has been given in this case, is the variation in the discharge of the river, due to a rise or fall of one foot in the lake; and it is necessary to know how much the quantity varies with the rise and fall of the lake of one foot, or any other unit, in order to determine the effect upon the lowering of a lake of the abstraction of water from the Chicago drainage canal, or any other diversion of water.

Q. Any diversion other than the ordinary outlet?

A. Other than the ordiary outlet.

Q. May an increment be determined for, say a river like the St. Clair river, the size of that river, by taking one discharge measurement when the lake is at a certain elevation, say 580, and another discharge measurement when the lake is at another elevation, say 581?

A. It could not be determined accurately in that way.

Q. What would be the difficulties in connection with the determination of an increment, with those two measurements?

A. The difficulty might rise with the current meter measurements of the river and the discharge, but are more likely to arise with the relation of the discharge to the stage of the lake.

As I am informed by the facts appearing in evidence in this case, and already testified to by the complainant's witness, Lakes Michigan and Huron and the other lakes do not remain quiescent, at a constant level, but they fluctuate in an irregular way, in the course of short periods and longer

periods; that is short periods, I don't know exactly how long, but of minutes or hours; and in longer periods, from day to day, from the effect of barometric changes and winds. The lake in general never keeps at a constant level, and to make accurate discharge measurements, to obtain the laws governing the flow of water in any channel, it is essential, in order to get the best results, that the flow should be uniform and continuous and not varying from time to time.

Q. Are there any greater difficulties attendant on making discharge measurements of a large river than there are in connection with making discharge measurements of a small stream?

A. Yes.

Q. You know the width of the St. Clair river at the different sections where discharge measurements were made, do you not?

A. I know approximately.

Q. Will you state what, if any, difficulties there are connected with making discharge measurements by the use of the current meter, and as those measurements may be referred to stage of lake?

A. The difficulties are greater in a large stream than in a small one, for the reason that in a small stream, such as I have had occasion to measure myself, the current meter can be placed upon a rigid handle or pole, put down into the water in an exact position, and held so that it will face the current; while in a deep river, especially where there is a swift current, the current meter must be attached to a cord. It has to depend upon a vane or tail to maintain its direction, and hence may not be at right angles to the line of the cross section where the measurement is being taken.

There is also greater difficulty in determining whether the current meter is at the depth indicated by the depth of the lines by which it is suspended, as one cannot see its position. It certainly is less definite in location than where it is on the end of a rigid pole, which will not bend.

I think there is one other feature that may have some bearing in this case, namely: That current meters for measuring the discharge of large rivers with swift currents are necessarily of heavier construction than some of the meters used for measuring the discharge of small channels.

The difficulty in connecting discharge measurements with the stage of the lake is, as already stated, the difficulty of maintaining a steady flow in the stream. It is bound to vary

with the frequent changes in the lake level, which introduces considerable uncertainty into the results; and they may not be nearly as accurate as they appear to be from a comparison of different measurements. This has been thoroughly indicated by the comparisons to which I have testified between the gagings at different points upon the same river; that is, at the St. Clair, Niagara and St. Lawrence stations, which prove to my mind conclusively the difficulties in the way of obtaining the discharge corresponding to different stages of a lake.

If you had the two measurements, two discharge measurements to which you have referred heretofore, say of the St. Clair river when the lake was say at stage 580, and the other measurement when the lake was at say stage 581, you could derive an increment from that, couldn't you, from those measurements?

A. Yes.

Q. Would that increment so derived be accepted by engineers as having any value?

A. It would have very little value.

Q. Well, then, is it because of probable errors in the measurements and as referred to lake stages, or for some other reason?

A. One would not in any case, I think, wish to depend upon two measurements, because there might be an error in any part of them that would lead to uncertainty. It requires a much larger number before one would feel that even the possible mistakes had been avoided.

Q. What is the advantage of a large number of measurements, if any?

A. The advantage is in several ways: First, it shows the accuracy with which a measurement may be repeated as compared with a gage near at hand. Then, different results would be obtained, even if there were no frequent oscillations of the lake; that is due to wind and other temporary causes, or rising and falling stages of the lake. And the frequent measurements, if made both on the rising and falling stages, would to a certain extent eliminate errors which would appear, if the measurements were confined wholly to one or the other of these conditions.

Q. So that the errors, in one measurement, may be offset by errors in another, taking the mean of all?

A. The errors due to certain causes may be offset, but there still may be left errors which are not offset. The mul-

tiplicity of observations will tend to offset certain classes of errors.

Q. Might there be errors in all the measurements, that is similar errors in all the measurements, which would materially interfere with determining the correct result or increment?

A. Yes.

Q. What would you suggest as probable errors?

A. The full effect of changes in lake stage are probably not felt in a measurement taken in a river. For instance, to take an extreme case, if one were making measurements 100 miles down a river from a lake, there would be many fluctuations tending to increase and decrease the discharge through the river. And the effect of these fluctuations would be felt only to a limited extent at a point so far down the stream.

Q. Would that be true of a measurement of the river taken at a gaging section located at, say 75 miles, from the foot of the lake

A. I believe it would to a somewhat less extent than at a hundred miles.

Q. And the same would be true where the gaging section is within six miles of the foot of the lake?

A. Yes, but to a less extent.

Recess to 2 P. M.

After recess—2 o'clock P. M.

FREDERIC P. STEARNS resumed the stand and testified further as follows:

Mr. Adcock: Q. Would the agreement between the volume of the water measured at two gaging sections on a river, like the St. Clair, necessarily indicate the accuracy of the measurements made at either of the sections, or the increment derived from the measurements made with reference to the stage of lake, at either one of the sections?

A. In my judgment it would not.

Q. Will you give your reasons, if you have any, for that statement.

A. The agreement of measurements at two sections on a river would be an indication of the accuracy of the measurements as referred to a gage near by; but would not neces-

sarily show that the measurements were correct, or that the increment derived from the measurements was correct.

This has already been indicated in connection with the two sets of measurements in another river than the St. Clair; that is in the Niagara river, where the measurements of two sections agreed well, and yet the discharge and the increment derived from those two sets of gagings is not correct.

Q. On a large river like the St. Clair river, of that depth and velocity, etc., is it possible to determine the accuracy of the discharge measurements made, from any other source than from the precision or accuracy of the current meter measurements made, and the soundings and measurement of the cross-section, etc.?

A. Not at all precisely. The discharge of the St. Clair river can be deduced from gagings at another point on the river, in the manner that has already been included in my testimony; but one could not determine the gagings at that river with sufficient accuracy to be used as a basis for determining an accurate increment.

That is to say, an accurate increment could be obtained only by gagings on the St. Clair river, or some point near, and only if those gagings were sufficiently extended and sufficiently accurate to be trustworthy.

It is questionable whether the lake would ever remain at a sufficiently constant level for a sufficient time to enable wholly trustworthy measurements to be made, as referred to the stage of the lake.

A limited number of measurements, made without reference to whether the lake was remaining at a nearly constant level, or was fluctuating considerably through the action of winds and other causes, would not give as good results as a series of measurements made at different elevations of the lake surface, when the lake surface remained nearly constant.

For instance, if an attempt were made to obtain the discharge for a high level of the lake caused by a strong wind blowing towards the outlet of the lake, it would not give results as satisfactory as if the lake were at the high stage for a period of weeks.

Q. Are the results of a series of measurements by the use of the current meter such as is shown by the records of measurements on the St. Clair introduced in evidence, approximate or absolute results?

A. I do not know the local conditions in that case well enough to answer the question; that is, as to the character of

the current meters used, and the extent of the irregularities of the current.

Q. Would it be possible to get an absolutely accurate result by current meter gagings, in any case?

A. I think that absolute accuracy cannot be obtained by any kind of gaging. A close approximation to accuracy may be obtained by several kinds.

Q. And where the river is large, those difficulties, as you have stated before, are increased?

A. Yes.

Q. Is it necessary, in view of those conditions, if possible, to refer the results obtained to physical conditions, conditions of rainfall, evaporation, etc., in order to determine and test their accuracy?

A. It is desirable to do so, but not necessary in many cases, as with moderate currents and conditions which obtain in the measurements of some large rivers, the actual measurement by the current meter can be quite well checked by a comparison of two sections. But in referring the measurements to lake stages, I think it very important that there should be a check where there can be.

For instance, gagings have been made of the St. Clair river and of the Detroit river, which is practically a continuation of the same stream with only a small lake and a small drainage area between, and such comparisons as could be made in those cases are important as checking the accuracy of the measurements; and yet such comparisons do not do away with the difficulty of properly relating the discharge measurement to the lake stage.

Q. Do you have any record of any discharge measurements made in the Detroit river?

A. I have not examined them. I know that they have been made, and that they were used by the International Waterways Commission on the Regulation of Lake Erie, in making a comparison between the discharge of the Detroit river and the discharge of the Niagara river.

Q. Do you know when those discharge measurements were made at the Detroit river?

A. In 1901 and 1902, as stated in the Annual Report of the Chief of Engineers for 1903, Appendix FFF, pages 2814 to 2817.

Q. Were those discharge measurements made about the time discharge measurements were made on the St. Clair river, the records of which have been introduced in evidence?

A. They were made at about the same time as the first set of measurements on the St. Clair river, which were made in the years 1889 to 1902.

Q. Do you know whether or not the discharge measurements on the St. Clair river were used by the International Waterways Commission in making up the report of 1910 on the Regulation of Lake Erie?

A. They were not so used except on occasions when the measurements indicated that the Detroit river was blocked with ice, and at such times the St. Clair measurements were used.

Q. Do the fluctuations of the stage of lake have any relation to the increment?

A. Yes.

Q. What is the relation?

A. The greater the fluctuation of the lake, meaning by this term not the small fluctuations, or the short period, but the fluctuations in longer periods is substantially inversely, other things being equal.

Q. That is, the greater the increment, other things being equal, the less will be the fluctuations?

A. Yes.

Q. And vice versa, the greater the fluctuations, you would expect a less increment?

A. The less increment.

Q. Is the discharge of the St. Clair river affected in any manner by the rise or fall of Lakes St. Clair and Erie, or either of them?

A. It is.

Q. Just explain, will you please, how the discharge may be affected?

A. The discharge of the St. Clair river, assuming Huron to remain constant and the St. Clair lake to rise, the effect would be to diminish the slope of the water between these two lakes, and that diminution of slope would diminish the speed with which the water would pass from one lake to another; and hence would diminish the quantity flowing. And similarly, the lowering of Lake St. Clair would increase the quantity flowing. The same is true of Lake Erie; a rise in Lake Erie will increase the level of Lake St. Clair, with a given quantity of water flowing, and hence would have the effect through St. Clair upon the discharge through the St. Clair river. That is the effect is first felt in Lake St. Clair,

raising that lake and consequently affecting the flow through the St. Clair river.

Q. Can you determine a proper increment, then, from discharge measurements of the St. Clair river, as referred to the stage of lake, without taking into consideration the stage of Lake St. Clair as compared with Huron?

A. No, not unless St. Clair maintains a constant relation to Lake Huron.

Q. Where you have a number of discharge measurements, and it is possible to group the discharge measurements, when Lake St. Clair is at a constant stage, is it proper to determine an increment therefrom for the St. Clair river, as affected by Huron alone?

A. Yes, as a step in the determination of the increment for the St. Clair river, with both lakes St. Clair and Huron having their normal relations.

Q. What would be the next step, then, to determine the correct increment for St. Clair, if you find a number of discharge measurements made when Huron was at a constant stage?

A. And Lake St. Clair changing?

Q. And Lake St. Clair changing.

A. That also would give an increment for Lake St. Clair, which could be combined with the increment for Lake Huron obtained by the previous method, and furnish a proper increment, in one way, for the St. Clair river.

Q. I refer you to Tables XXII, XXIII and XXIV, Williams Exhibit 34. Have you made any examination of the manner in which those tables were made up and the results shown on those tables?

A. I have.

Q. Referring to Williams Exhibit 34, Mr. Stearns, will you indicate such of the tables on that exhibit as you have examined, and know the methods of their compilation?

A. I think I have examined all of them and know the methods of computation.

Q. Referring to Tables XXVIII to XXXIX inclusive of Williams Exhibit 34, will you state whether you have examined those tables, and whether you consider the basis of computation and the results reached from those computations correct?

A. I have examined the tables, have considered the basis of computation, and believe that the results obtained are correct, for the assumptions made.

1031

In some cases the results are deducted from two assumptions, and obviously both cannot be correct.

I would say in regard to these tables, and others made by Mr. Williams and introduced as a part of Exhibit 34, that I have not checked the accuracy of any of the numerical computations.

Q. That is, your answer is on the assumption that the computations have been accurately made, and that the discharge measurements referred to were accurate?

A. Yes.

Q. In those tables the discharge measurements are grouped chronologically, are they not, for substantially the same stage of lake?

A. They are, in Table XXVIII and Table XXXIV.

Q. The Table XXVIII refers to the discharge measurements of the St. Clair river from 1899 to 1902, does it not?

A. It does.

Q. And the Table XXXIV, 1908 to 1910?

A. Yes.

Q. And tables 29, 30, 31, 32 and 33 are based upon Table 28, is that correct?

A. Yes.

Q. And Tables 35, 36, 37, 38 and 39 are based upon Table 34?

A. Yes.

Q. Do you consider that the method of treating the observations in the tables referred to XXVIII to XXXIX inclusive leads to more accurate results than the method of treating them without reference to chronological grouping, with reference to the similar stage of the lake for each group?

A. This is not only a chronological grouping, but also one in which the lake stages are nearly constant, and it necessarily eliminates some of the observations. If, however, it does not eliminate too many of them, I believe this method is the most correct, in that it deals with nearly constant stages of the lake, and with observations which were made near together, in point of time.

Q. Why is it necessary to use observations where the lake was nearly constant, and refer to the same time?

A. It is better to do so, and more accurate results could be obtained, because while the lake is falling rapidly, or fluctuating at short intervals, the results would not be as good as if there were a more constant stage of the lake.

Q. Referring to Table XXXIII, columns 8 and 9 of that table, where the increment is derived mathematically, do you consider that a proper method of deriving the increment?

A. I do.

Q. Do you consider that method more accurate than to plot the discharge measurements, and then from the position of the discharge measurements upon the plate, pass a string through to indicate the mean line?

A. Where the different measurements should be given even weight, there is no method of obtaining the line of an increment better than the method used in columns 8 and 9 of Table XXXIII, and in many other of the tables in Williams Exhibit 34, by determining the center of gravity of all the points, and the centers of gravity of the upper and lower half; that is, the upper and lower parts into which the main center of gravity divides the results.

Q. In considering the discharge measurements to determine the increment, do you believe it necessary to give the groups of measurements equal weight?

A. No, they should not be given even weight, where they represent different number of observations or different number of days, but as a part of the determination, these observations in Table XXXIII have been weighted in accordance with the number of days represented by each group of observations, and after they had been so weighted, I see no reason why each should not be given equal weight.

Q. Is there any other method as good as the method which is pursued in Table 33 for deriving the increment?

A. There is no method that is the more correct, where the observations should have equal weight. The method of using a thread or string, in connection with a plot, should give very nearly the same results, but this is the more perfect method to get exactly the right line.

Adjourned to Thursday, March 27, 1913; 9:30 A. M.

Thursday, March 27, 1913; 9:30 A. M.

Met pursuant to adjournment.

Present same as before.

FREDERIC P. STEARNS resumed the stand and testified further as follows:

Mr. Adcock: Q. Referring to Table XXVIII of Williams Exhibit 34, where 81 observations of discharge measurements on the St. Clair River, during the period from 1899 to 1902, are grouped chronologically and according to substantially the same stage of lake for each group, and assuming that those 81 observations extend over the entire period during which the discharge measurements were made, and assuming that there were approximately 265 measurements in all, do you consider that the 81 used in Table XXVIII are sufficient to give reasonably accurate results in the determination of the increment for the St. Clair River?

A. The number is sufficient to give accurate results if the observations are accurate, and that number—

Q. That is, assuming that the observations were accurate?

A. And while I have not examined the selection of these experiments from the whole number, I should think that they would give better results than the whole number if they represented nearly constant stages, and those experiments which were rejected represented more variable conditions in the lake.

Q. That is when you say "represented," you mean were taken at a time when the lake stage was varying?

A. Yes, when the lake stage was varying to a considerably greater extent.

Q. At what rate do the fluctuations of a lake decrease, as compared with the increase of an increment?

A. They decrease in a direct proportion as the increment increases, other conditions remaining constant.

Q. As compared with the increase of increment, at what rate does the discharge capacity of an outlet to a lake increase?

A. The discharge at a given stage of the lake increases at least as rapidly as the increment increases.

Q. So that the enlargement of a channel, causing an increase of discharge at the same stage, results likewise in the increase of increment, as a general proposition?

A. It does as a general proposition, under nearly all circumstances.

Q. Assuming that from say 1860 to 1910, the outlet of Erie remained unchanged so far as the discharge capacity was concerned, how would you determine the relation of mean annual fluctuations of Huron in the period from 1891 to 1910 both inclusive, to those similar fluctuations of Huron during the period from 1860 to 1889?

A. The method shown in Table 21 of Williams Exhibit 34 appears to me to be a proper one. In this table, for the period from 1860 to 1889, the years were arranged in the order of the height of Lake Huron, and the corresponding heights in Lake Erie were recorded in another column for the same years that the heights are given for Lake Huron. The line representing the fluctuations of Lake Huron, and also of Lake Erie, was determined by the center of gravity method, which has been so fully described; and the relation of the fluctuations in Lake Huron to those in Lake Erie were determined, as set forth in that table, to be in such proportion that 75.3 per cent. of the fluctuations of Lake Huron were represented by the fluctuations of Lake Erie.

The observations from 1891 to 1910 inclusive, were arranged separately in the same order, and following precisely the same processes. It was found that during this period the fluctuations of Lake Huron were represented to the extent of 86.1 per cent. in Lake Erie. By comparing the 75.3 per cent. and the 86.1 per cent., it will be found that the fluctuations of Huron in the later period were 87½ per cent. of the fluctuations in the earlier period.

In both cases this is determined on the basis of the conditions contained in your question, that the discharging capacity of Erie remains unchanged.

Q. That is, you mean by the discharging capacity of Erie, the outlet to Erie remains unchanged?

A. Yes.

Q. Why do you use Lake Erie as a comparison, that is, the fluctuations of Erie?

A. The difference in fluctuations in the two periods might otherwise be due to differences in the quantity of water and the rain fall. And by using Lake Erie as a standard, and bearing in mind that by far the greater part of the water discharged from Lake Erie comes from Lake Huron, and that the wet and dry years would be likely to affect both Lake Huron and Lake Erie in a similar manner, I reach

the conclusion that Lake Erie may properly be used as a standard for determining the relative fluctuations of Lake Huron in the two periods.

Q. Assuming that as stated in your answer to the preceding question, Huron has fluctuated 14 per cent. more in the earlier period, that is, from 1860 to 1889, inclusive, than it did from 1891 to 1910, inclusive, what do you say as to whether the discharging capacity of the St. Clair and Detroit rivers was greater or less in the former or in the later period?

A. It was greater.

Q. Assuming that the discharge of the St. Clair river was 197,600 cubic feet per second at certain stage of lake during the latter period, that is stage of Huron, what would have been the discharge of the St. Clair river at the same stage during the earlier period?

A. I cannot give a definite amount, but on the basis that the discharge at a given stage increases at least as rapidly as the increment increases, and since the increment varies inversely as the fluctuations, it would not have been more than 87½ per cent. of 197,600 cubic feet per second, equal to 172,900 cubic feet per second.

Q. What would then be the difference between that and the discharge in the former year?

A. Not less than 24,700 cubic feet per second.

Q. Assuming that the increment of the St. Clair river during the latter period was 28,872 cubic feet per second, what then was the increment of the St. Clair river during former period?

A. 25,300.

Q. How much, if any, then, was Lake Michigan lowered by the enlargement of the channels of the St. Clair and Detroit rivers, assuming that the increment in the latter period was 28,872 cubic feet per second, and the increment in the former period was 25,300 cubic feet per second?

A. The average increment during this period would have been 27,100 cubic feet per second, and as the difference in the discharging capacity of the channel as above estimated was not less than 24,700 cubic feet per second, the lowering would have been not less than 24,700 divided by 27,100, equal to .91 of a foot, or substantially 11 inches.

Q. How does the result which you have reached, when you have considered the effect of the enlargement of the channels of the St. Clair and Detroit rivers by comparing the fluctuations of Huron from 1891 to 1910, both inclusive, with

the fluctuations of Huron from 1860 to 1889, both inclusive, coincide with the results reached and shown by Stearns' Exhibit 1, tables A. B. C. D. E. F. and G, and the results shown by your testimony heretofore given, in connection with Stearns' Exhibit 1?

A. The testimony referred to, based upon Stearns' Exhibit 1, was to the effect that there had been an increase in the the discharging capacity of the St. Clair and Detroit rivers from the period including the years from 1883 to 1888 as compared with the period including the years from 1892 to 1903, of from 17,800 to 27,900 cubic feet per second. The average of those two quantities is 22,850 cubic feet per second, which may be compared with the amount of not less than 24,700 cubic feet per second obtained by the method based upon the relative fluctuations of Lake Huron in the periods 1860 to 1889, and 1891 to 1910.

Q. In other words, you have arrived at practically the same results by two entirely different methods, have you not?

A. I have, except in this one particular; in one case it represents not less than a given sum, while in the other case, the quantities are fairly well defined between limits.

Q Do you consider that the results reached, which are substantially the same by the two entirely different methods which you have described, are in any manner a corroboration of the results of either?

A. I do.

Q. Give your reasons for that latter answer?

A. I regard the first method, that is, the one based upon the discharge of the St. Lawrence, to be the better one, the more certain one, but the other one, is based upon correct principles, and should give an approximate result, and it does confirm the other.

Q. Well, do you consider that each result may be a confirmation of the other?

A. Yes.

Direct examination of this witness adjourned.

Further hearing of testimony in said matter adjourned sine die.

Saturday, July 26, 9:00 A. M.

FREDERIC P. STEARNS, a witness called on behalf of the Sanitary District, having been previously sworn, testified as follows:

Direct Examination by Mr. Adcock.

Q. Do you know Mr. Stearns to what extent the dilution method of sewage disposal is now utilized in cities of the United States, as compared with other methods?

A. I do in the larger cities.

Q. Will you state the comparisons?

A. Taking the 19 largest cities, there is only one which does not use the dilution method. All others use it. And of the 15 cities next in size, having a population of more than 146,000, all use the dilution method with the exception of four.

Q. How do they treat the sewage?

A. By various methods. I can describe that in detail, if you wish it now.

Q. I think you might as well, yes.

A. Of the 19 largest cities, all of which have a population of more than 250,000, Baltimore is the only one, as I have said, which uses other than dilution. And Baltimore treats its sewage by taking it to sprinkling filters located some six or eight miles north of the city near the Back River, and there purifies it by what is known as the sprinkling filter method.

This system in Baltimore has just been adopted within the last few years and is only in partial operation at the present time. The city had no system of sewers, and in establishing a new system they were required by the charter to purify the sewage, with a view to not affecting the oyster industry in Chesapeake Bay, which is a very great industry.

Shall I mention the others?

Q. Yes.

A. The smaller cities of those already mentioned which treat their sewage are Providence, Rhode Island, which had a population in 1910 of 224,000, and it uses a chemical precipitation process for treating sewage, and subsequently disinfects the effluent with hypochlorite of lime before it is discharged into tide water at the head of the Providence River.

Columbus, Ohio, population in 1910, 182,000, has a system of sprinkling filters with their usual appurtenances for the

treatment of its sewage. These works were constructed and are operated for the purpose of preventing offensive conditions in the Scioto River at times when the flow is insufficient to properly dilute the sewage.

At other times the sewage goes untreated by dilution, and they not only discharge into the stream the whole of the sewage, but they wash out into it the matters they have taken from the sewage previously. It is wholly a question of preventing a nuisance in a certain place, and not with regard to its effect upon the water supplies below.

Atlanta, Georgia, population in 1910, 155,000, has recently begun to purify a part of its sewage by means of sprinkling filters and their appurtenances, so as to prevent offensive conditions in three small streams.

Q. Are they connected in any way with the water supply?

A. I don't know in regard to that, but the statement is made in the official reports that it is to prevent offensive conditions, and I presume there is no question of water supply from those streams; there should not be.

Worcester, Massachusetts, population in 1910, 146,000, uses the chemical precipitation process for a part of its sewage, filtration through land for other parts and also filters through land a part of the effluent from the chemical precipitation works. All of this is for the purpose of preventing offensive conditions in the Blackstone River, in which the quantity of water is entirely inadequate for properly diluting the sewage.

Q. To recur for a moment, the cities that you have mentioned come within the class known as the class of 15 cities smaller than the great metropolises of the United States. Will you recur to the larger cities in which the population is over 250,000?

A. Yes.

Q. Such as New York?

A. Yes.

Q. And state the condition?

A. One of the cities was in this 19 larger cities.

Q. Which one was that?

A. Baltimore.

Q. Now take up the larger cities such as New York, Chicago Sanitary District, Philadelphia, and so forth.

A. I have here a table giving the population in 1910 of these cities. In two cases I took the Sanitary District—

Q. As a municipal corporation which it is.

A. As a corporation, rather than the city.

Q. The sewerage district?

A. Yes, sir.

Q. Also the Boston sewerage district you treat as a city?

A. Yes, sir. The list is as follows, in order of the size of the city:

New York,	4,767,000
Chicago Sanitary District,	2,312,000
Philadelphia,	1,549,000
Boston Sewerage District,	1,277,000
St. Louis,	687,000
Cleveland,	561,000
Baltimore,	558,000
Pittsburg,	534,000
Detroit,	466,000
Buffalo,	424,000
San Francisco,	417,000
Milwaukee,	374,000
Cincinnati,	364,000
Newark,	347,000
New Orleans,	339,000
District of Columbia,	331,000
Los Angeles,	319,000
Minneapolis,	301,000
Jersey City,	268,000

Q. Mr. Stearns, you have now mentioned the 34 larger cities of the United States, have you not?

A. Yes.

Q. Of these 34 larger cities of the United States, I understood you to say that all but five at the present time use the dilution method of disposal of sewage, is that correct?

A. Yes.

Q. And those five that use a method other than the dilution method have no connection with any water system?

A. They have not as I believe.

Q. The effluent from purification works, whatever they may be, is not discharged into any water supply of that city or other cities?

A. It is in the case of Columbus, but the purpose of purifying the sewage is not to protect the water supply, because at seasons of the year all the sewage goes into the stream, and they wash also into the stream, as I stated, the matters removed from the sewage at other times. It is wholly for the purpose of preventing offense.

Q. To what extent was the dilution method of sewage disposal used in the United States between 1885 and 1890?

A. Well, it was used by all of the large cities which had sewage disposal systems.

Q. To what extent were other methods of sewage disposal utilized, both in America and abroad, prior to 1890?

A. The use of other methods in America prior to that time was very limited. Sewage from certain public institutions, and from a few small towns, was disposed of by irrigation upon or filtration through land. The more notable places were the sewage farm at Pullman, which was not successful, largely on account of the impervious character of the land, and the sewage disposal area for the Village of South Framingham, Massachusetts, which was successful, as the land consisted of coarse sand well adapted to filtration. This system however was not operated until near the end of 1889.

At Los Angeles, and probably at other places in the arid regions, sewage was used during the irrigation season to promote the growth of crops, but the prime object in these cases was not the disposal of the sewage but the raising of crops. During a portion of the year the sewage was disposed of by dilution.

In the large cities abroad, much more was done prior to 1890 in the matter of sewage purification, mainly for the purpose of avoiding a nuisance where large cities were located upon comparatively small streams. In London, the offensive condition of the Thames led to the introduction of chemical precipitation works for clarifying the sewage. At Berlin, the sewage was purified by irrigation. At Paris, part of the sewage was purified by irrigation and filtration through sandy land, the remainder being discharged into the river Seine.

The dense population of England and the large amount of manufacturing wastes, taken in connection with the small sizes of the streams, made necessary many works for treating the sewage before it was turned into the streams. These works included broad irrigation upon land, a few cases of intermittant filtration through sand and several chemical precipitation plants, as well as a variety of methods of straining the sewage through coke and other materials. Many of the plants which existed in these places prior to 1890 have since been abandoned or materially modified as methods better, adapted to the conditions existing then, have become available.

Q. Referring back to the Baltimore plant, Mr. Stearns, you stated that one of the prime objects of that system was to protect the oyster industry in Chesapeake Bay. Is that correct?

A. Yes, sir.

Q. A separate system of sewers, from which the storm water was excluded, was adopted in Baltimore under their system?

A. It was.

Q. And all the sewage was collected by intercepting and main sewers and carried out to a point near Back River where sprinkling filters and other appurtenances were constructed, is that correct?

A. Yes; that is the work has not been completed yet. It is only a small part of the city sewage that now goes there.

Q. The appropirations for the work and for drain for the removal of storm water amounted to how much if you know?

A. I think the amount was $20,000,000.

Q. Did that system deal in any way with the contamination of the harbor waters?

A. It did in this way that the sewage was intercepted and prevented from entering the harbor and carried to these other points. The storm water and street wash still goes into the harbor.

Q. And to that extent, that is the street drainage and polluted brooks and so forth which flowed through the city into the harbor, was not contemplated in the improvement, the protection of that or the purification of it?

A. It was not except as these brooks will be improved somewhat in their condition by the interception of the sewage which now goes into them, the domestic sewage.

Q. At the time of this appropriation and the contemplated improvement Baltimore had no system of sewerage, did it?

A. It did not.

Q. They were starting just like a new municipality?

A. Yes.

Q. Isn't it a fact that the sewage is discharged so far from the oyster beds that it would probably be purified by dilution before it reached them anyway?

A. It will; the purification by dilution is a very important factor in that plant.

I was a member of the Commission of Advisory Engineers who recommended the plant, and one reason for going to this Back River was that sewage could be discharged there less thoroughly purified than if it were discharged nearer where the oysters are; and it would obtain a further purification by dilution on account of the long distance that it would travel before reaching the oysters.

Q. So that you do not rely upon the purification works entirely to eradicate the impurities of the sewage?

A. That is true, as the works are built, and also in accordance with recommendations of this Commission. There was a secondary purification that was provided for in the original plan by filtration through land, and that is not being carried out, it being thought that the purification due to dilution will accomplish the purpose.

Q. Is there anything about the topography of Baltimore that made it possible to use this sort of method better than most any other city?

A. Yes, the conditions there are extremely favorable to sewage disposal. Baltimore is a hilly country, and as a consequence the sewage from by far the greater part of it can be carried with sewers having good grades by gravity to these sprinkling filters, and the whole process completed by gravity. Now, from a portion of the city it is necessary to collect the sewage by intercepting sewers down near the water front, and pump that portion of the sewage, but by far the greater part is easily carried to the works by gravity and by comparatively small sewers, because of the high grades.

Q. Did Baltimore have a convenient outlet for the discharge of the effluent?

A Yes, I should say so because the distance is not very great, and there was a good line on which to construct a sewer leading to these sprinkling beds.

Q. And these sprinkling beds were so far removed that under ordinary conditions the water containing this sewage effluent would not reach any spot that would affect the oyster beds?

A. Not for a very long time.

Q. Mr. Stearns you made a compilation showing the 19 largest cities and sewage districts. Have you totaled the population of those 19 cities or districts for the year 1910?

A. I have.

Q. What was the aggregate population?

A. The aggregate population of the 19 cities was 16,195,000. The population of the city of Baltimore was 558,000, or 3.4 per cent. of the aggregate population of these cities.

Q. I understood you to say that this Baltimore plant is still under construction, and just what the service will be is problematical to some extent at least?

A. Yes, and in any case only a very small part of the sewage of Baltimore is now purified. That is it would be

pretty near a true statement to say that almost none of the sewage of the 19 largest cities is at the present time purified.

Q. Have you considered the adaptability of other methods of sewage disposal for a city such as Chicago?

A. I have.

Q. Will you give us your views as an engineer and expert upon that question?

A. The situation is extremely unfavorable for any other system of sewage disposal than that which the city of Chicago now uses. It is impracticable to obtain a water supply for the city from any other source than Lake Michigan, and in no other way can the water supply taken from the lake be as well protected from contamination as by the present general method of sewage disposal, which not only keeps the sewage from entering the lake but creates a constant tendency to draw from the lake any water that may become contaminated along its shores, and it keeps from the lake the necessarily contaminated water of its rivers.

The usual methods of sewage disposal which could be considered if an outlet draining from the lake were not available are:

1. The thorough purification of all of the sewage before it enters the lake.

2. The partial or thorough purification of a part of the sewage before it enters the lake.

3. The discharge of crude sewage into the rivers and lakes.

Q. Will you take up and consider these different methods, in the order in which you have mentioned them?

A. The thorough purification of the sewage before it enters the lake—

Q. That is system number 1 that you have indicated, or method number 1?

A. Yes, with a view to eliminating all danger to the water supply, is impracticable in a city already provided with a combined system of sewerage, on account of the enormous cost and the inability to provide complete protection of a water supply in this way. The complete purification of the sewage cannot be accomplished with a combined system of sewers, meaning by the words "combined system" one which takes in the same sewers the sewage proper and the storm water. The quantity of mingled sewage and storm water discharged from such a system during heavy rains is so great that at such times the whole volume flowing cannot be puri-

fied by any practicable means. No community has ever attempted such complete purification.

It is the rule where such sewers are in use to provide for the purification of the dry weather flow of sewage and, in addition, the storm water flow from light rains, but at times of heavy rains a part of the mingled sewage and storm water is permitted to overflow with practically no purification into some convenient stream or body of water.

The purification of all of the sewage can be accomplished only when the sewage is collected in a separate system of sewers from which the storm water is excluded. Even with such a system in a city like Chicago, it would not be feasible to keep all contaminating matters out of the rivers and lake. Rivers in the midst of such a populous district, and used by ships, cannot fail to become contaminated and to require an artificial current to prevent them from becoming offensive, which would force the contaminated water from the rivers into the lake. During rains all of the street wash and storm water would necessarily be turned into the lake or into the rivers and thence into the lake.

As one of the consulting engineers engaged to advise as to a method of sewage disposal for Pittsburg, Pennsylvania, which would protect the water supplies of communities on the Ohio River below Pittsburg, I had occasion to study the problem of the complete purification of all the sewage. The first necessary feature was a separate system of sewers, in addition to the combined system already in use by the city. The estimated cost of installing the separate sewers in that city was $14,900,000. Pittsburg in 1910 had a population of 534,000, hence the estimated cost was $27.90 per inhabitant.

On the same basis the cost of providing a separate system for the 2,312,000 inhabitants of the Sanitary District of Chicago in 1910, would be $64,500,000. This sum does not include the whole of the burden which the community would suffer as the result of digging up every street in the city in order to lay the additional system of sewers.

The estimated cost at Pittsburg for providing the intercepting and main sewers to intercept and convey to the sewage disposal works the discharge from the separate system of sewers, of a pumping station to lift the sewage to the disposal works, and of the disposal works, amounted to $22,400,000, which is substantially $42 per inhabitant in 1910. In this case, the works were planned as they would be in any case to provide sufficient capacity for a reasonable time in

the future, the pumping stations and disposal works for a population 50 per cent. in excess of the population in 1910, and the main and intercepting sewers for a population rather more than three times the population in 1910.

Estimating the cost for the Sanitary District of Chicago at the same rate per inhabitant as at Pittsburg gives $97,-000,000 as the estimated cost of main and intercepting sewers and pumping purification works, which added to the $64,500,000 already estimated for the separate system gives a total of $161,500,000 as the first cost of works for completely purifying the sewage of the Sanitary District.

In addition, such works must be operated and extended from time to time. The estimated annual cost of operation at Pittsburg was $435,000 equal to $0.81 per inhabitant in 1910. On the same basis per inhabitant, the cost to the Sanitary District of Chicago would be $1,870,000 annually, which capitalized at five per cent. would be $37,400,000, making the total cost, including the capitalized operating expenses $198,-900,000.

In comparing the conditions which would affect the relative cost of works at Pittsburg and Chicago, I do not find any reason why there should be a radical difference in the cost per inhabitant at the two places and therefore believe that the above estimate gives an approximate idea of the cost of installing a separate system and of constructing and operating main and intercepting sewers, pumping stations and purification works for the Sanitary District of Chicago.

The above estimate does not include the cost of works for producing an adequate artificial current in the Chicago River, and it is well to state once more that even if the sewage removed by a separate system of sewers were thoroughly purified, the polluted river water which the artificial current would force out into the lake and the storm water contaminated with street washings from so large a territory would probably render it unsafe to use the water supply taken directly from the lake by the present methods.

I regard this method of sewage disposal, as already stated, to be impracticable on account of its excessive cost, and it would not adequately protect the water supply from contamination.

Q. What is the second method that you have above referred to?

A. The second method is the partial or thorough purification of a part of the sewage before it enters the lake.

A more practicable method of sewage disposal than that above described would involve the use of the present system of combined sewers, the interception of the dry weather flow and a small amount of storm water, in addition, and the treatment of the sewage so intercepted, with the ultimate discharge of its effluent into the river or lake. With such a system, it would be necessary to protect the water supply by sterilization or filtration, preferably by filtration. This method would furnish a safer water supply than would be afforded by the first method if the water supply in that case were not to be sterilized or filtered and should not cause any local offense, except in the vicinities of the sewage disposal works.

The cost of the sewage purification by this method, as compared with the first, would be diminished by a large part of the cost of the separate system of sewers, as the increased cost of main and intercepting sewers, pumping stations and disposal works, due to the necessity of providing for a limited amount of storm water, would be only a small part of the cost of installing a separate system. The remaining cost, however, would still be a very great sum of money, amounting on the basis before given to $134,400,000 for the main and intercepting sewers, pumping stations and purification works. The additional cost for the increased size of the works required for the removal and disposal of a small part of the storm flow might be offset by the diminution of cost due to the less thorough purification of the sewage by this plan.

Q. Will you take up the third method that you have referred to?

A. The third method is the discharge of crude sewage into the lake.

With this method of sewage disposal, the main purpose would be to prevent offensive conditions at any place. If a strong artificial current were to be created in the Chicago River flowing towards the lake, similar to that now created in the opposite direction by the Chicago Drainage Canal, it might continue to be feasible to discharge the existing sewers into the river, although the screening or sedimentation of the sewage might be necessary to prevent offensive conditions along the lake shore near the mouth of the river. In other parts of the city, it might be necessary to collect the sewage by intercepting sewers, and pump it through pipes discharging at several out-lets so far out into the lake that

it would become diffused and finally purified by the dilution method.

The difference between this method and the one in which only the dry weather flow of sewage is purified is one of degree only, because some crude sewage would reach the lake in either case and the water supply would have to be protected by sterilization or filtration or by both.

If the policy of discharging crude sewage into the lake were to be adopted, it would be advantageous to discharge all of the sewage south of the Chicago River and to take the water supply through intakes located well out into the lake, opposite some thinly settled part of the lake front north of the City Limits. This separation of sewage outlets and water supply inlets would diminish the opportunity for the mixing of the sewage and water supply, and would permit a considerable purification of the sewage by the various processes which accompany a high degree of dilution before the water receiving the sewage had time to reach the water works intakes.

Intermediate between the second and third methods of sewage disposal as here outlined, it might be possible to remove many of the floating and suspended particles in the sewage by screening or sedimentation, or to destroy some of the disease germs contained in the sewage by the use of a disinfectant, without carrying the sewage a long distance to sewage purification works. But none of these modifications would affect the general proposition that sewage disposal works other than by the method now used would necessarily cause the lake to receive much matter injurious to the quality of the water supply which is now kept from it.

Although there is abundant evidence that the filtration of water is an important safeguard and that a water supply which has caused many deaths from typhoid fever before it was filtered may be made reasonably safe by filtration, there is no direct evidence that filtration even when properly conducted wholly eliminates the danger from the use of contaminated water, and if the filtration is not properly conducted, there is obvious danger to the health of the water takers from the use of such water.

It is upon this ground that I have in the past and still advise against the use of a contaminated water after filtration, when it is practicable to obtain a purer source of supply. For instance, in 1894, I made estimates of the cost of the additional works for the water supply of the Boston Metropolitan District of Massachusetts, and recommended that an

unfiltered supply be taken from an unpolluted source at a first cost of $19,000,000, in preference to a filtered supply from a slightly polluted source at a first cost of $14,900,000, to which may be added $2,600,000 as the capitalized cost of operating filters and pumping stations in the last project. I then made this statement, which still represents my views:

"Even if it were admitted that sand filtration with scientifically constructed filters and intelligent management will entirely remove disease germs from water, there is still the chance in the administration of a work of this kind that the preparation may be unscientific and the management unintelligent, which may cause the water to be either imperfectly purified by filtration, or, by accident, carelessness or the necessity of maintaining the supply, sent to the Metropolitan District without any filtration whatever."

It is, in my judgment, useless to say that in a problem of this kind the sanitary conditions only are important and that the cost is unimportant. The two cannot be divorced one from the other under the common sense practical conditions of municipal government. Many important sanitary conditions are desirable but they cannot be realized because of the direct relation of sanitation to cost. The resources of a city or district are necessarily limited, in some cases by law and in some cases by practical conditions. The enforced use of a vast sum of money for a given sanitary purpose, even if it were possible to obtain such sum by borrowing or taxation, would necessarily limit the amount which could be used for other sanitary purposes.

It is therefore in my judgment impossible for the Sanitary District of Chicago to reproduce by any other method of sewage disposal than that now used as sanitary conditions in relation to its water supply and sewerage as can be maintained by the use of the Chicago Drainage Canal, with the right to take from Lake Michigan the quantity of water commensurate with the needs of the District from time to time.

Q. Mr. Stearns, have you given consideration to the subject as to what extent prior to 1890 sewage was discharged into water used for drinking purposes, and the state of the art of water purification at that time, in America?

A. Yes.

Q. Will you state what your conclusions and views are upon that subject, and the facts pertaining to that subject?

A. Sewage was very generally discharged prior to 1890 into the largest rivers and the lakes from which water was

taken for water supply. There were, however, prior to that year, many smaller streams and rivers and lakes and ponds from which water was taken for drinking purposes and into which the disposal of sewage was prohibited; as, for instance, the streams, ponds and reservoirs used by the cities of New York, Boston and Rochester.

Prior to 1890, water purification, with a view to the removal of disease germs, could hardly be said to exist in America. There was before this date a small sand filtration plant at Poughkeepsie, New York, and a much larger number of so-called mechanical sand filters, most of them filtering at a high rate, using alum as a coagulant and operating under pressure.

The State Board of Health of Massachusetts began to experiment upon the purification of water by filtration through sand in the latter part of 1887, but the results were not published until 1890.

It may fairly be said that the available knowledge in regard to water purification prior to 1890 was nearly all based upon the practical work which had been done along these lines in England and in other parts of Europe.

Q. Have you made a study of the history of sewage and water purification in the United States?

A. Yes.

Q. And are familiar with the methods of sewage disposal of the cities of the United States having a population of over 250,000?

A. Yes.

Q. Will you state the facts concerning those two situations?

A. The history of sewage and water purification in the United States may almost be said to begin with the experimental work of the State Board of Health of Massachusetts, begun in 1887. There were, as already stated, sewage purification plants for certain public institutions, and a few very small towns prior to this time, and the Pullman Sewage Farm had been constructed. Moreover, a number of engineers and health authorities had studied conditions in Europe and had made reports upon the methods of sewage disposal in use there.

The experiments of the State Board of Health furnished for the first time a scientific basis for sewage disposal by filtration through sand and gravel, and demonstrated the limitations of some other methods. The experiments of this Board have been carried on continuously from 1887 to the

present time and have furnished an increasing amount of knowledge with regard to the various methods of water and sewage purification.

The construction of systems of sewage disposal in many places in the United States, using a variety of methods which have been developed by experimental and practical work in this country and abroad, has added greatly to the information regarding sewage disposal and purification, and has at the same time developed many sanitary engineers who can determine with a fair degree of accuracy the results to be obtained by the adoption of different methods.

As a result of this progress in the art of sewage disposal, if Chicago had constructed works for disposing of the sewage by any other method than dilution on the basis of the information of 1890, it probably would have had only a small measure of success, and would have found it necessary to entirely remodel the works.

While there has been a great advance in methods of sewage disposal since 1890, a further advance is to be expected. With all the knowledge now available, the disposal of the sewage of a great city is a difficult and very expensive problem unless it can be accomplished by the dilution method, and it is for this reason that the dilution method is used almost universally, wherever there is an opportunity to use it.

In regard to water purification, there were the mechanical filters and the Poughkeepsie Filter already referred to before 1887. The experiments and investigations of the State Board of Health of Massachusetts resulted in the completion in 1893 at Lawrence, Massachusetts, of the first large sand filtration plant in the United States, the city having at that time a population of 48,000. The results obtained with this first large filter were under continuous observation by experts, and it was soon found that the water filtration greatly diminished the death rate in the city from typhoid fever and reduced to a considerable extent the death rate from other diseases.

Many causes, of which the results obtained by this filter were one, lead several large cities having water supplies from polluted rivers to agitate the question of the filtration during the decade ending in 1900, and many experiments were made under the direction of experts and with many kinds of water, which added greatly to the available information regarding water purification.

Among these were experiments at Providence, Rhode Island, in 1893-1894; Louisville, Kentucky, in 1895; Pitts-

burg, Pennsylvania, in 1897; Cincinnati, Ohio, in 1898; Washington, D. C., in 1899; and New Orleans, Louisiana, in 1900. These experiments furnished information as to the relative merits of slow sand filters used without a coagulant and of rapid sand filters using a coagulant and as to the character of the waters to which each of these types was best adapted.

The next large filter for the purification of the water of a city, after that of Lawrence, was put in operation in Albany, New York, in 1899.

This was followed by filters for other cities, which were first put in operation at the following dates:

Philadelphia, Pa.; Little Falls, N. J. 1902
Providence, R. I. 1904
Washington, D. C. 1905
Louisville, Ky.; New Orleans, La.; Pittsburg, Pa.; Cincinnati, Ohio; Denver, Colo. 1907
Columbus, Ohio 1908

In addition to these filtration plants and many others for smaller cities, St. Louis, Missouri, began to clarify and purify its water by the addition of a coagulant and subsequent sedimentation in large settling basins in 1904, and the East Jersey Water Company began to sterilize the water it supplied to Jersey City by the addition of hypochloride of lime in 1908.

To sum up the history of water purification for large cities, it may be said that prior to 1890 the knowledge was mainly that derived from European experience. The decade ending in 1900 was one in which much was learned by experimental work and a little by actual operation of large water filtration plants.

The decade ending in 1910 is one in which a large number of important water purification plants have been constructed and operated, adding much more to the fund of knowledge of water purification.

The present method of sewage disposal in the cities of the United States having a population of over 250,000 is, as already stated, by dilution in practically all cases. This method is frequently adopted for small communities without any expert investigations, because it is the easiest method of disposal, but in the case of the larger cities it has been adopted or retained after expert investigations. For instance, the City of Boston up to the year 1876 discharged its sewage at numerous outlets into the waters which surrounded the city, with the result that offensive conditions were produced. Expert investigations at that time showed that the best method

of disposal would be to intercept the dry weather flow of sewage, convey it in a main sewer to a pumping station where it could be lifted so that it would run thence by gravity to an outlet into the harbor at a favorable place about five miles from the city, where it would receive a proper degree of dilution.

In 1888 the State Board of Health of Massachusetts was instructed to consider the problem of the proper disposal of the sewage of the other cities and towns of the Boston District and some portions of Boston not provided for by the original main drainage works. This Board after investigating in detail the available methods of sewage disposal recommended the dilution method for this additional Boston District.

Still later, when the original main drainage works of Boston became overtaxed, a further investigation was made which resulted in a third main system of sewers, discharging at a point where the sewage could be satisfactorily disposed of by the dilution method.

In all of these large cities, with the exception of Baltimore, the changes which have been made in sewage disposal have been in the line of obtaining better dilution and not a departure from the system of sewage disposal by dilution.

Q. Mr. Stearns, in considering the methods that you have referred to, do climatic conditions enter into such consideration?

A. They do.

Q. Will you state your views upon that subject?

A. In disposal by dilution, climatic conditions have very little to do with the case. Sometimes there is a covering of ice that makes a little trouble by keeping the sewage or the polluted water away from the air and the oxygen. But in the case of any other method, except possibly chemical precipitation, the cold weather of winter such as is experienced at Chicago makes the problem much more difficult, that is difficult to obtain purification, and very much more expensive and troublesome than where there is a warmer climate.

In Baltimore, for instance, there will be very little trouble from ice, in connection with the sprinkling filters, but in a place like Chicago ice would form over the beds to such an extent as to render them very much less effective, if it didn't actually put them out of commission.

Q. Have you given consideration to the necessity of keeping the water supply free from raw sewage pollution or effluent?

A. Yes.

Q. Will you state your views and conclusions upon that subject?

A. Abundant evidence has been obtained since 1890 to show that if water polluted by raw sewage goes directly into the water pipes of a water supply system, within a few days after the sewage enters the water much sickness and many deaths will occur among the water takers. One of the first striking proofs of this in the United States was furnished by the City of Lawrence, Massachusetts, where the deaths from typhoid fever before the water filter was put in operation were many times in excess of the deaths from the same disease in other cities having an unpolluted water supply.

That this was due to the water supply was clearly shown by the great decrease in the death rate from typhoid fever after the filters were put in operation. Similar results have been found where other cities have begun to filter their water or where they have changed from a polluted to an unpolluted water supply.

I have here a table headed "Death Rates per 100,000 of the Population Before and After the Filtration of the Water." The table is as follows:

Death Rates per 100,000 of the Population Before and After the Filtration of the Water.

	Before.		After.	
Lawrence,	121	(5 years)	26	(5 years)
Albany,	104	(5 years)	26	(5 years)
Cincinnati,	53	(3 years)	12	(4 years)
Columbus,	63	(4 years)	17	(3 years)

One of the most definite cases of sickness and death caused by a water supply which received raw sewage occurred in the manufacturing city of Lowell, Massachusetts. The mills of that place have a joint supply for manufacturing purposes, which is contaminated by sewage and under somewhat greater pressure than the city supply. On the occasion of an extensive fire, the connection between these two systems was opened, and although check valves were provided to prevent the water in the mill pipes from passing into the city pipes, a large quantitv of contaminated water passed into the city pipes owing to some defective apparatus. In the section of the city which this contaminated water entered, typhoid fever began to develop in about 13 days, and in the course of a month 161 cases had been reported, with a total in four months of 231, resulting in 10 deaths.

This epidemic was undoubtedly caused by the contami-

nated water, as it was limited to the section of the city which received this polluted water and the disease was first noticed the proper number of days after the date when the water in the pipes was infected.

Such evidence shows clearly both the necessity of keeping the water supply free from raw sewage pollution, and that a water supply can be protected to a large extent from the effects of sewage pollution by the filtration of the water.

If the Sanitary District had in 1890 adopted a purification process before discharging the sewage into the lake, it would probably have adopted the process of chemical precipitation, a process which was adopted in 1892 for the treatment of the sewage of the Columbian Exposition at Chicago. Such a process would have protected the water supply only to a limited extent. Modern processes such as sprinkling filters when properly operated remove a large percentage of the bacteria, and with subsequent sedimentation and sterilization, the effluent may be made nearly free from disease germs, but it should be kept in mind that no process of purification in connection with a combined system of sewers can prevent raw sewage from being discharged during heavy rains to endanger the water supply.

Q. Have you given consideration to the minimum amount of water required to properly dilute sewage?

A. Yes.

Q. Will you state your conclusions upon that subject?

A. In 1889 I wrote a paper on this subject, which was published in the Special Report of the State Board of Health of Massachusetts upon the examination of Water Supplies, 1890. At that time, I reached the conclusion from the limited data then available that where the volume of water was less than 2.5 cubic feet per second per 1,000 persons, offensive conditions would be created and that with more than seven cubic feet per second per 1,000 persons offensive conditions would not be created.

None of the cases upon which these conclusions were based included the waste from slaughter houses.

In 1902, a further examination was made by the State Board of Health with much more data than was available in 1889 and the conclusion was reached that under some circumstances "Objectionable conditions may not result where the dilution is somewhat less than 6 cubic feet per second per 1,000 persons; but objectionable conditions have resulted in all of the cases thus far examined where the flow has been less than 3.5 cubic feet per second for 1,000 persons discharg-

ing sewage into the streams." (Report of State Board of Health of Massachusetts, page 452.)

For purposes of comparison, it may be stated that the Illinois law requires that the amount of dilution of the Sanitary District sewage shall not be less than 3⅓ cubic feet per second for each 1,000 of population, and that the recommendation in the original report of Messrs. Hering, Williams and Artingstall was that there should be a dilution equivalent to 4 cubic feet per second for each 1,000 of the population.

From all of the information available except that derived from the Chicago Drainage Canal itself, I should have concluded that 3⅓ cubic feet of water per second was less than the proper amount for the dilution of the Chicago sewage, including as it does strong sewage from the Stock Yards and slaughter houses, but the best information available is that derived from the Chicago Drainage Canal itself.

The report of the sewage disposal made to the Board of Trustees of the Sanitary District of Chicago by George M. Wisner, Chief Engineer, on October 12, 1911, gives the result of many observations, showing that the dissolved oxygen is exhausted from the water and putrefactive conditions are created in the downstream half of the Drainage Canal in the summer time when the quantity of water flowing from the lake through the canal is substantially the minimum quantity required by the State Law. These observations show that the 3⅓ cubic feet per second per 1,000 of population is not enough to properly dispose of the sewage under the existing conditions, although it approximates the required amount.

This statement refers mainly to the summer time, but since the time when I made that conclusion from Mr. Wisner's report, I have been down the Chicago Drainage Canal in warm weather, although not in the hottest weather, and I was satisfied from my inspection of the canal that more than 3⅓ cubic feet per second was required to properly dilute the sewage in the summer season.

Mr. Wilkerson: Q. How much more, Mr. Stearns?

Mr. Adcock: 3⅓ cubic feet per second per thousand people?

A. Per thousand people. It is difficult to say how much more, from mere observation. The date of my visit was May 27, not the warmest weather, and at that time it seemed to me that the quantity of water which was flowing, which was substantially the 3⅓ cubic feet per second, was as little as could be used.

Mr. Wilkerson: Q. How much water was going through at the time you mentioned?

Mr. Adcock: The presumption is the 3⅓ cubic feet per thousand.

Mr. Wilkerson: The presumption is there was 4,162 cubic feet taken out of Lake Michigan. All I care for at this time in the record are the figures upon which Mr. Stearns based his statement, at the time he made his inspection. He understood there was substantially 3⅓ feet. I want to know whether he was merely told that by someone, whether it is all right or whether he was given the figures on which he based the statement.

Mr. Adcock: Q. How did you get that information as to the 3⅓ cubic feet at that time?

A. I received that information in a letter.

Q. In a letter? From the Sanitary District?

A. Yes.

Q. Or from someone connected with the Sanitary District?

A. From someone connected with the Sanitary District.

Mr. Wilkerson: On what basis do you figure the present population of the Sanitary District, how many inhabitants? What do you figure it is now?

Mr. Austrian: I understood about 2,300,000.

Mr. Wilkerson: That would make about 7,666 cubic feet per second you were taking?

Mr. Adcock: Q. These oyster beds that they undertook to protect at Baltimore, to preserve the industry, and to keep the germs from filtering to those spots and polluting the oysters, were located something like 20 miles from the City of Baltimore, were they not?

A. I don't think they were as far as that from the City of Baltimore, but from the sewage outlet.

Q. I mean from the sewage outlet at the City of Baltimore?

A. They were located something like that distance. I should say from 15 to 20 miles. I have not the exact distance.

Q. You have made an exhaustive study of this subject, I understood you to say, in your previous examination, and as disclosed by this examination; and you have inspected the Drainage Canal, and you have familiarized yourself thoroughly with the various systems for taking care of sewage disposal. You are also familiar with the topography of the City of Chicago, I take it, Mr. Stearns, in a general way?

A. Yes.

Q. And the expense of the territory covered by the Sanitary District, in a general way?

A. Yes.

Q. You also are generally familiar with the climatic conditions in Chicago?

A. I am, yes, sir.

Q. And the location of the water used for health purposes, the intakes and the like in the City of Chicago?

A. Yes.

Q. From all your investigations, and from the facts concerning which you have testified, have you reached any conclusion as to whether any system for sewage disposal other than the one now in use, that is by means of the Sanitary District, is a practical, feasible, proper, efficient method for sewage disposal for that district?

Mr. Wilkerson: You include in that question the element of the cost of construction?

Mr. Adcock: I said all the facts and circumstances.

Mr. Wilkerson: I did not know whether you were going to have the thing rejected as improper because it cost so much.

Mr. Adcock: Q. Have you reached a conclusion?

(Question read.)

A. I believe the method in use is by far the best method; and I think it is also the only practicable method, practicable and efficient method of taking care of the sewage and protecting the water supply; but there may be some combinations of purification, or there may be some partial purification of the sewage which could be used in connection with the present method. But I do not see how the present method could be abandoned, or greatly restricted in the quantity of water, and obtain results that should be obtained.

Cross-Examination by Mr. Wilkerson.

Q. Have you made any computations based upon the assumption that the Sanitary District is permitted to take from Lake Michigan 4,167 cubic feet of water per second for the purposes of this canal, and utilize that in taking care of part of the sewage disposal, and combining with that proper works which would take care of the sewage of a population in excess of the amount which could be handled by taking care of 4,167 cubic feet of water from the lake?

A. I have considered the matter.

Q. And have you reached any conclusion about it?

A. Yes.

Q. The 4,167 cubic feet a second would take care of how large a population, on the basis of 3⅓ cubic feet per second, per thousand inhabitants?

A. 1,250,000.

Q. That would leave about a million people in the district unprovided for, on that basis?

A. It would at the present time; but the population is growing, so that million would increase rapidly.

Q. So far as growth is concerned, it is only a matter of a few years when the district, even if it uses 10,000 cubic feet per second, will have to provide some other way of taking care of the additional population?

A. On that same basis, 10,000 cubic feet per second would provide for 3,000,000 people; but it is easier to provide new arrangements as the city grows for additional population than it is to reconstruct works already in existence.

Q. Now with reference to the cost of your plant, you gave some figures based on the experience of Pittsburg?

A. Based upon estimated figures for Pittsburg, not upon actual experience.

Q. And what was the result per capita? That is, I cannot carry these figures in my mind; I am leading up to the question: The population of Pittsburg was how much?

A. The population of Pittsburg, 534,000.

Q. 534,000, and the estimated cost of the contemplated works, including cost of maintenance capitalized, was how much?

A. It was $86.10 per inhabitant.

Q. The total amount was how much?

A. $46,000,000 for Pittsburg.

Q. Now, to provide for a city of 1,200,000 on the same basis would cost how much?

A. That is another city of 1,200,000?

Q. Yes, another city of 1,200,000.

Mr. Adcock: I object to that. I do not see as it has anything to do with this case; it is not pertinent to any inquiry.

A. $103,000,000.

Q. That will be $103,000,000 on the same basis that it cost to provide for the disposal of sewage of a 1,200,000 city, so that even if the Drainage Canal could be utilized to take care of the sewage of a million two hundred thousand people, the expense for that part of the sewage disposal is smaller than it would have been if the other methods had been adopted at that time?

A. The figure that I gave of one hundred and three million dollars was for a city of 1,200,000, and not for a part of the city. I do not think it follows that the conditions would be the same.

Q. You did use that as the basis for your computation as to what it would have cost in Chicago for a system of the same kind as designed for Pittsburg?

A. Yes, for Chicago as a whole.

Q. For Chicago as a whole?

A. But not as to the cost for a part of it.

Q. My question is based upon the assumption, if we had at Chicago a city of only 1,200,000 in place of a city the size that we have, the cost—

A. On that basis?

Q. —on that basis would have been $103,000,000?

A. Yes.

Q. On the same basis as you applied in making the estimate of the cost for the entire City of Chicago?

A. Yes, sir.

Q. I think it is stated here that the figures for the cost of the Sanitary Canal are between seventy and seventy-five million dollars?

Mr. Adcock: You can assume $75,000,000.

Mr. Wilkerson: Q. And then as against the cost of maintaining a sewage system such as the one that was contemplated for Pittsburg, there would be, so far as Chicago was concerned, a credit which would come from the use of the water power derived from the water which was taken from the lake.

Mr. Austrian: That would depend on whether the water power was utilized at a profit or at a loss.

Mr. Wilkerson: That would be an element as against the cost of maintenance of one method as against the other?

A. The estimated cost of sewerage works for the complete purification of the sewage of Chicago, based upon the estimates made for Pittsburg, did not include the use of any water from the lake. Hence there is no water power question that comes into that.

Q. Obviously, I did not make my meaning clear. I was contrasting the expense which the City would have been put to for 1,200,000 of its population if it had used a method similar to the one which was contemplated for Pittsburg, with the situation where it was able to utilize for 1,200,000 of its population the water to a limited extent from the lake. And what I had in mind was this: That with the system which

was devised for Pittsburg, with the cost of maintenance, which was pretty large, is it not a rather large cost of maintenance?

A. Yes.

Q. With a system of that kind, with the method of diluting the sewage by the water taken from the lake, if that water was utilized for power purposes, or any other similar purpose, there is a credit there rather than a cost of maintenance?

A. No.

Q. What is your opinion as to the cost of maintenance of the two methods, as an engineer familiar with projects of that kind?

A. The cost of operating sewerage works is more than could ever be obtained from water power, in my judgment, taking the whole cost, but it may be a feature in favor of a dilution method that there is some small rebate obtained, or may be obtained from the use of the water for power.

Q. It costs more to maintain a system such as was devised for Pittsburg than it does to maintain a dilution system such as there is in Chicago, does it not?

A. Yes, certainly.

Adjourned to Monday, July 28, 1913, at 10:00 o'clock.

July 28, 1913, 10:00 A. M.

Cross-Examination of Mr. Stearns Resumed.

Mr. Wilkerson: Q. Of the nineteen large cities which you mentioned Mr. Stearns as utilizing, with the exception of Baltimore, the dilution method of sewage disposal including Chicago, in how many of them is the sewage discharged into salt or brackish water? That is to say I want you to put those into a class by themselves.

A. Five.

Q. Which ones?

A New York, Boston.

Q. How about Philadelphia?

A. That is fresh water I believe. I am not entirely certain about that point. To continue: San Francisco, Newark and Jersey City.

Q. In the case of Philadelphia, the diluting body is not the source of the drinking water supply is it?

A. It is the source of the drinking water supply, but the sewage is, nearly all of it, put in below; and possibly all at the present time. Years ago it was not all put in below the point at which the water supply was taken.

Q. That is to say in the case of Philadelphia, you have a stream in which the drinking water is taken from the upper portion of the stream, and the sewage discharged at a point below that where the water is taken?

A. I think that is the case at the present time, but I am not certain. The points of taking the water and of discharging the sewage are not very far apart.

Q. What is the fact with reference to New Orleans?

A. New Orleans discharges its sewage, as I believe, into the Mississippi River but I am not sure but what some of it goes into Lake Pontchartrain. Both of them however are bodies of fresh water.

Q. How about the District of Columbia?

A. That is a fresh water stream. The sewage is discharged into the Potomac.

Q. And where does the District get its supply of drinking water?

A. From the Potomac above Great Falls. That is far above the tidal portion of the stream.

Q. All these streams at Philadelphia and New Orleans, the District of Columbia, the portions of the stream into which the sewage is discharged are tidal portions, as you understand it, so the water at times is brackish?

A. At New Orleans, there is no effect of the tide. At the other places there is a tidal effect but the water is never brackish, for the reason that the fresh water pushes the salt water down the stream, except possibly in the case of Philadelphia. I am not fully informed as to that.

Q. Now in the case of Los Angeles where is the sewage discharged?

A. I am not certain at the present time whether it may not be carried down as far as the tide water and possibly into salt water. Formerly it was discharged, as I believe, into a stream that led to the tide water.

Q. Now, of the nineteen cities which you named, which ones are on inland rivers?

Mr. Austrain: You mean located on inland rivers?

Mr. Wilkerson: Yes, or so situated that an inland stream has to do with the drinking water and sewage problems.

Mr. Austrian: And by an inland stream do you mean a stream—

Mr. Wilkerson: Like the Mississippi.

Mr. Austrian: Or the Chicago River?

Mr. Wilkerson: No, I do not mean an inland stream running the wrong way from what it would run naturally.

Mr. Austrian: The Chicago River is certainly an inland stream. The Chicago River is not a manufactured stream; it is a natural stream. I do not mean to complicate it, but I do not quite understand what you mean by an inland stream.

Mr. Adcock: Most all streams are inland, aren't they?

Mr. Wilkerson: Q. In order that Mr. Adcock may understand the question I will call your attention to the cities of St. Louis, Pittsburg, Cincinnati and Minneapolis, and ask you to tell us what the facts are with reference to those cities as to the drinking water supply, and disposition of their sewage in its relation to the body of water.

A. St. Louis discharges its sewage into the Mississippi River. I do not know the details, as to whether any of it is discharged above the point of intake of the water supply.

Q. It takes its water supply from the Mississippi does it?

A. Yes. Pittsburg discharges its sewage into the Alleghany and Monongahela Rivers, and also into the Ohio River, which is formed by the confluence of the other two.

Q. Cincinnati?

A. Cincinnati discharges its sewage as I believe, into the Ohio River.

Q. Before we come to Cincinnati, where does Pittsburg get its water supply?

A. It gets it from the Alleghany River near the upper portion of the city of Pittsburg.

Q. Now Cincinnati?

A. Cincinnati takes its water supply from the Ohio River.

Q. And where does it discharge its sewage?

A. I believe it discharges it into the Ohio River, but I don't know the details as to where the outlets are.

Q. And Minneapolis?

A. Minneapolis discharges into the Mississippi River.

Q. And it gets its water supply from what river?

A. The Mississippi River above Minneapolis.

Q. Now let us take two larger cities; let us take Detroit and Buffalo. Give us the particulars about their supply of drinking water and sewage disposal.

A. The drinking water of Detroit is taken from the Detroit River and the sewage is discharged into the Detroit River, I presume, at a point below the place where the drinking water is taken. What is the other one?

Q. Buffalo?

A. Buffalo takes its water supply from Lake Erie. And its sewage is discharged into Lake Erie, or the waters that flow from it.

Q. Now take the remaining cities of these 19 and we have 3, do we not, which originally had the same problem; that is to say a city lying on the lake brim, with the lake as the source of water supply, and as the basin into which the sewage was discharged, Chicago, Cleveland and Milwaukee?

A. Yes.

Q. Of the 15 smaller cities of 146,000 population or more, how many of those discharged their sewage into salt water, or water usable as a water supply, either unusable as a water supply or unnecessary as a water supply, as for instance at Portland, Oregon?

A. I haven't the list of those cities with me.

Q. Now let us eliminate all cases where the potable quality of the diluting basin or stream is not involved for present use, or use in the near future, how many cities remain which are utilizing the dilution method without any treatment, either screening or purification of the sewage?

A. Doesn't that eliminate every case?

Q. In how many of the cities which you have named is the water with which the sewage is diluted used in connection with the water supply of that city?

A. In Cleveland.

Q. How about Milwaukee?

A. Milwaukee.

Q. Columbus?

A. That is not on my list.

Q. How about Rochester, New York?

A. In Cleveland and Milwaukee, of the nineteen larger cities.

Q. Do you know the facts about Toledo, Ohio?

A. I know that the sewage is discharged into the lake and the water supply is taken from the same lake.

Q. Now, is there any treatment of the sewage at Cleveland?

A. There is not so far as I know.

Q. Do you know as a matter of fact whether at Cleveland the hypochlorite treatment is in contemplation?

A. I think it has been in contemplation for the water supply.

Q. How about Milwaukee?

A. In Milwaukee, a report has recently been made by a

Sewerage Commission of three engineers, and they have proposed treatment of the sewage. I do not think there is any treatment at the present time.

Q. It is in contemplation, as you understand it?

A. Yes.

Q. Or under investigation? What is the practice as to the water supply and sewage disposal of Duluth?

A. I am not certain, from memory.

Q. West Superior?

A. I don't know about West Superior. It is the general custom of all those cities to take the water supply from the lake.

Q. Do you know the facts at Toronto?

A. To some extent; that the water supply is taken from Lake Ontario. I understand that it is filtered now, and the sewage is turned into the lake.

Q. Is the sewage screened or purified there, or the water supply treated chemically or filtered?

A. I think the water supply is treated by filtration. I don't know in regard to the sewage.

Q. Now you have spoken of the work which was done in this country in sewage purification prior to 1890. Is it not a fact that prior to 1890 the work done in England, Berlin and Paris, and in other places where the density of population had resulted in nuisance and unsanitary conditions, that this work was well known and had become accepted practice?

A. It was well known, but had hardly reached the point of being accepted practice. There was very frequent changes in methods, and different engineers had radically different views.

Q. It was undergoing what might be called a process of rapid development, was it not?

A. I should rather put it rather slow development at that time.

Q. Of course the terms "rapid" and "slow" are relative terms. What might be rapid for one thing would be pretty slow for another.

A. (No response).

Q. You are familiar with the reports of engineers Herring, Williams and Artingstall, made in January, 1887, to the Mayor and City Council of Chicago?

A. I knew about the report at the time, and I have read it once since.

Q. If you have a copy of the record in this case, you will

find it commencing on page 261 at the top of the page of the printed abstract of the record?

A. I haven't that with me.

Q. I will refer you to a particular part: I refer you to page 278 of the printed abstract of this testimony, as prepared by the counsel for the defendant in the case; the paging at the side is 861. I will ask you whether you have in mind the fact that those engineers outlined three feasible methods of disposing of the sewage.

Mr. Adcock: You mean whether they concluded that they were feasible?

Mr. Wilkerson: Three feasible methods, yes. I asked him whether he had that in mind in connection with his—

The Witness: Will I wait, and get it in mind?

Q. I wanted to know first whether you had it in mind when you testified on Saturday.

Mr. Adcock: Are you stating their conclusion?

Mr. Wilkerson: Q. I am quoting the language in the report in which these three distinguished engineers say: "We have outlined the main features of the only three feasible methods of disposing of metropolitan sewage."

A. I did not.

Q. I wish you would read that Mr. Stearns.

A. (After referring to same.) I have read it.

Q. Now, have you read that portion of the report in which after stating the features of the three different methods of disposing of the sewage, it is stated with reference to the proposed construction of the canal, "That this project is decidedly the least expensive one for the present, as well as for the future."

A. What is the reference to that?

Q. Page 280.

A. Yes.

Q. Are you familiar with the work of the three gentlemen whose names are signed to this report, Mr. Hering, Mr. Williams and Mr. Artingstall?

A. I am with regard to the work of Mr. Hering; not with regard to the others, except to a limited extent.

Q. He is regarded as an engineer whose opinion is entitled to some weight in your profession?

A. Entitled to great weight, but I should add that he had not the fact and information to base an opinion upon in 1887 that he would have at the present time.

Q. That is obvious.

A. Nor the experience.

Q. Is it your opinion that the trend of practice in sanitary science is towards the avoidance of the discharge of crude sewage into rivers, lakes, and even the sea?

A. The discharge of sewage has to be governed by local conditions, and a city that is situated upon the sea can discharge its sewage into the sea under many conditions. One situated upon the lakes may have to discharge it into the lake. The trend is not away from dilution, in my opinion.

Q. Is from it?

A. It is not away from dilution.

Q. It is not away from dilution. I am speaking of crude sewage now, which is not treated or purified in any way before it is turned into the lakes or rivers?

A. That is what I have in view. Perhaps, in order to explain a little more fully, I should say that the trend is quite decidedly in favor of purifying sewage in cases where it will cause a nuisance in a stream. That is people are not as ready to recommend creating a nuisance in a stream as they formerly were.

Q. That is to say if you have a stream where the amount of water available for diluting purposes is not sufficient to meet the requirements of the pure dilution method, the tendency is to treat the sewage in some way before it is discharged into the water, so that a given quantity of water will handle more sewage?

A. Yes.

Q. And that is a well recognized, and a very rapidly, or slowly developing branch of your profession is it not?

A. The growth of population on small streams is forcing the purification of sewage, in order to avoid a nuisance.

Q. That is to say the volume of the stream is not sufficient to handle the sewage?

A. Where the volume of the stream is not sufficient to properly dilute the sewage.

Q. And where you have a stream of that kind, even though the quantity of water available is rather small, it is recognized as a problem with which you may hope to cope successfully if the sewage is properly treated before it is turned into the water, is it not?

A. It can be coped with in practically all cases, if the treatment of the sewage is made adequate to the necessities of the case. That is I know of some very small streams which receive the effluent from sand filtration, where the sewage is almost perfectly purified, and no nuisance is caused.

Q. Are you familiar with the contemplated purification and screening of the sewage of Pittsburg?

A. I am familiar with the sewage problem in Pittsburg, but I don't think anything of that sort is contemplated at the present time. I was one of the Commissioners to report upon that case. I was very familiar with the Pittsburg case from having been engaged upon it, but do not know any such thing was contemplated. I understand it is not contemplated at present.

Q. Are you familiar with the method which is used for handling the sewage of London?

A. To a limited extent. I visited the chemical precipitation works at Barking.

Q. I wish you would describe that to us in a general way.

A. London provided many years ago a system of rather small intercepting sewers, which overflow into the Thames with any considerable storm. Whether they have supplemented those or not I do not know. My information dates back a number of years. This intercepted sewage from the combined system of sewers is carried, on the north side of the Thames, to Barking, which is quite a number of miles below the center of London; and there it was at that time treated with chemicals, to a rather limited extent. Then it is passed through settling basins in which the solids were supposed to settle, and did settle to a very considerable extent; and then the effluent flowed out, at a place where I saw it discharged, and it looked just about as bad as the sewage that was turned in. But evidently there was a large amount of solid matter taken out of the sewage at that place. This was pumped up by means of pumps into high tanks, and from them it was discharged into ships or lighters, ocean-going craft, that carried it down beyond the mouth of the Thames and dumped it into the sea.

Q. How long ago was this when you—

A. That was in 1899 that I made that visit. I have not been at the works since.

Q. Have you any information as to how many gallons they treated in London?

A. I think that substantially all of the dry weather flow, and while I am not sure what that is, it is approximately 250,000,000 gallons. I am judging that from the amount of the water supply.

Q. Do you know the cost per year per capita of treating that sewage?

A. No.

Q. Do you know the cost of the works?

A. No.

Mr. Adcock: Q. Was the purpose there to purify the sewage, or was it really to take the solids out?

A. It was to prevent a nuisance in the Thames.

Q. By simply taking the solids out?

A. Yes.

Mr. Wilkerson: Q. By purifying it, wasn't it?

A. It could hardly be called purifying. It was settling a part of the solids in these tanks, and the sewage went on with a very large part of the bacteria, disease germs, if there were any, in it.

Q. What are the conditions at Berlin?

A. I am not at all familiar with Berlin. I have not visited it. There was an irrigation farm there years ago, and it is still there so far as I know. Very extensive farm, on which the sewage was treated.

At that time the quantity of the water supply—and this dates back 25 years anyway—was about 30 gallons per inhabitant; a very small total quantity of sewage, considering the size of the city.

Q. They conserve their water; they do not waste it?

A. Yes, and do not use it very freely either.

Q. What are the conditions in Paris?

A. I am not familiar with any recent conditions in Paris. Years ago they irrigated to some extent, and to some extent filtered through sand, but the greater part of the sewage was turned into the Seine River.

Q. Now as to the purification of the supply of drinking water, is it not a fact that as early as 1890 water purification was practiced successfully, and on a large scale, in England and on the Continent?

A. It was practiced on a large scale, and I should also say successfully in England and on the Continent, but it was done by a rule of thumb method, rather than with a thorough knowledge of the processes. That is the knowledge of disease germs, and that they transmitted typhoid fever was rather limited at that time.

Q. But it was practiced?

A. It was practiced.

Q. You have stated certain conclusions as to the degree of dilution of crude sewage necessary to avoid offensive conditions, and as I remember, expressed the opinion that in the summer months at least, the legal requirement of the

Illinois law for the Drainage Canal is not sufficient. Did I understand you correctly?

A. Yes, it is nearly sufficient, but not in my opinion as much as it should be for the hot months.

Q. And in the winter months you think that a smaller amount of water could be gotten along with?

A. I think so at times, except when the streams are frozen over so that they will not take up oxygen from the air. It may be that fully as large a quantity would be required in winter, under those circumstances.

Q. What in your judgment would be the proper ratio for the month of August?

A. I have not definite enough information upon that to fix a definite quantity. I went over the canal in May, and I read the records of the absorption, of the reduction of dissolved oxygen, and it seemed to me that the quantity of water run was rather insufficient. There is no hard and fast line. It is a question of how much an odor coming from the water the communities below will stand. But it was my general judgment that it should be more than the quantity that is fixed by law.

Q. How much less could be gotten along with in January than in August?

A. As I have said, it might be necessary to have as much in January as in August, on account of the freezing over of the stream. There are some intermediate periods where less could be used.

Q. Take November.

A. But I have never attempted to define the amounts. I have not studied the question sufficiently.

Q. Of course by varying the amount which is used from month to month, the available supply of water could be still further conserved, could it not?

A. It could.

Q. That is, use less in one month than in others, and bringing the annual average up to a certain point?

A. That would be much better than to make a hard and fast rule of a uniform quantity throughout the year.

Q. You referred in your direct examination to the report of Mr. Wisner, the Chief Engineer of the Sanitary District. I wish you would refer to page 8 of that report, and notice particularly the paragraph on page 8 headed: "Condition of Canal." It says: "At present there is a large deposit of sludge in the forebay of the power house extending over two miles north to the controlling works and into the rock

section" and then further along it speaks of "Gas Ebullition." Were any of the offensive conditions which you noticed in those portions of the canal in which sludge deposits have formed, as stated in this paragraph?

A. The odor was most noticeable in the portion close to the Bear Trap Dam, and from there down to the power works, and especially where the water was going over the dam near the power house.

Q. Did these sludge deposits do you think have anything to do with the offensive condition of the canal?

A. Yes.

Q. If the sewage of Chicago were screened, a gain in the quantity of dilution necessary would be made?

A. I could not answer that question because I have not studied it.

Q. There would be a gain would there not?

A. Yes.

Q. That is to say if I understand you, if the sewage were screened, it would not require as much water to handle a given quantity of sewage as would be required if it were not screened?

A. Yes, if the screens were made fine enough to take out the solid matter.

Q. If, in addition, settling tanks were utilized to remove the finer suspended matter, would there be a still further gain?

A. The use of anything, either settling tanks or screens that would take out what I should call the coarser suspended matters would be a gain.

Q. If in addition to this the dry weather flow, and that of light rains, were adequately treated with hypochlorite, would that still further make a gain in the quantity of dilution that was necessary?

A. I do not know what the effect of hypochlorite would be upon the sewage effluent. I should think it might do harm as well as good.

Q. What would be the effect of proper treatment of the industrial waste of the Stock Yards District, assuming those great concerns were required to treat the matter before it was discharged into the sewer system?

A. When I examined some of those works, they were treating the industrial wastes, so that that treatment was already in effect.

Q. When you made your examination?

A. Yes.

Q. Do you know to what extent they practice it?

A. No, I saw them running the effluent through settling basins and taking off the grease and taking up some material from the bottom, which had settled.

Q. Of course the proper treatment of that by these great concerns is a factor in this problem?

A. Yes, if it can be accomplished.

Q. Right at the close of your testimony on Saturday, we had some figures in the record with reference to the cost per capita, on the assumption that 4,167 cubic feet per second would, under the Illinois law, take care of the requirements for a population of 1,250,000 people. I want to get that figure now, assuming that the cost of the canal was $40,000,000, how much would it be per capita?

Mr. Austrian: For how many inhabitants?

Q. For 1,250,000.

A. $32.

Q. $32 per capita?

A. Yes.

Q. And at a cost of $60,000,000, assuming the cost of the canal to be $60,000,000, it would be $48 per capita?

A. Yes.

Q. Do you know what the cost of the water supply of Chicago is compared with that of New York and Boston, to the people of the city?

A. No, except that it is less.

Q. The cost per capita in both New York and Boston is very considerably larger than it has been in Chicago, is it not?

A. I think so.

Q. But you do not have in mind the figures which would enable you to state that comparison with any degree of accuracy?

A. No.

Q. Or approximately so?

A. No.

Q. Let us assume Mr. Stearns that this canal with a flow of 4,167 cubic feet per second remains a part, a permanent part of the sewage disposal works of Chicago, having in mind the highest possible use of the canal as a sanitary canal purely, and having in mind the avoidance of offensive conditions to the health and well being of the people in the Des Plaines and Illinois Valleys, and at St. Louis, what use would you say should be made of that quantity of water, so that the utilization would be the highest possible? And let me direct

your attention in that connection to, first, the restriction of any water waste in the city of Chicago. What do you think could be done to reduce that?

A. In answer to the first question, if the City of Chicago were limited to that amount, a part of it should be used possibly to dilute crude sewage from those districts where it would be most difficult to purify it, and another part should be used to take care of the effluent from sewage which had been partially purified. But the quantity would be very inadequate, in my judgment, as an offhand judgment to prevent nuisance and trouble, or very undue and impracticable expense for purification of the sewage.

Q. What do you mean by "undue and impracticable expense"?

A. With so small a quantity of water, it might be necessary to go to an expense for sewage purification before the sewage was turned into the canal, which a city could not meet as a practical condition.

Q. If this quantity of water were utilized for the treatment of the sewage of a portion of the city, how could the sewage of the portions which were not included in that system be treated? Could you use sprinkling filters?

A. That would be one method.

Q. Could you use separate sewers in the unsewered portion of the city?

A. Yes, if it proved advisable, it could be done.

Q. And the sewage could be purified and discharged into the lake; that would be still another method?

A. I think it would be more advisable to turn it into the current running from the lake, in any case.

Q. Have you made any study of the hypochlorite treatment of water supply?

A. Not a special study. I have never applied it in any of my work, but I know it is used.

Q. Have you given consideration to the cost of the use of such a treatment of the water supply, as an accessory to a canal, with 4,167 cubic feet per second as the maximum limit?

A. Do you mean the treatment of the water supply taken from the lake?

Q. Yes?

A. I have not made any figures in regard to that.

Q. Is it not a fact that without screening, or sedimentation and chemical treatment, the water dilution of the Drain-

age Canal is not used with as high a degree of economy as is possible?

A. Yes.

Q. Without that, it is not being as economically used as would be possible if they did screen?

Mr. Adcock: You mean economy in the use of water?

Mr. Wilkerson: I mean economy in the use of the water of the lake for purposes of sanitation.

A. A smaller amount of water could be used if the sewage were treated and somewhat purified before being discharged into the canal, but that involves expense and difficulty, especially for the part of the sewerage system which is already established.

Mr. Adcock: Q. You are speaking now without reference to the run-off of the drainage area of the Chicago river in High water times, etc.

A. Yes.

Mr. Wilkerson: Q. Having in mind the fact that Chicago has been increasing very rapidly in population, even with an allowance of 10,000 cubic feet per second, Chicago is bound to be face to face with that question some time, isn't it?

A. Yes, it is practically face to face with that question now because in any question of improvement of conditions of sewerage, one has to consider the time necessarily used to produce those new conditions; and 10,000 cubic feet will be needed, even if works were to be started as soon as they could be under any municipal conditions; as soon as they have been, in any other city.

Q. And is it not a fact, without regard to what the difference in expense is, that the question of the use of 4,167 cubic feet per second, or the question of the use of 10,000 cubic feet, is entirely and absolutely one of cost?

A. No, that is not true, as I believe. The canal was built for 10,000 cubic feet a second, and I believe has a still larger capacity. And it was built to reverse the current in the Chicago River, so that that river which receives sewage should not be turned into the lake. And time is an important element in producing any change in sanitary conditions; and I do not believe that if the quantity were diminished to 4,167 cubic feet per second, that the city could catch up with those conditions, even. If the quantity had been fixed originally, they might possibly have purified the sewage to the extent so that they could get results from that quantity which were fairly satisfactory, except for the reversal of the river currents. There is a necessity for reversing, also, in ordinary

times, the current of the Calumet River, in my judgment, so that the ordinary flow of the Calumet River should not be into the lake.

Q. If the sewage were purified and the waste properly taken care of according to modern scientific methods, along the Calumet, would there be any necessity in your opinion of reversing the flow of the Calumet?

A. It would be very desirable.

Q. Well, would it be necessary?

A. Practically so.

Q. Is it your judgment as an engineer that there is no way of adequately taking care of the sewerage problem of the Calumet District, without reversing the flow of the Calumet River?

A. I consider it so highly desirable that I think it should be done. I think it is impossible to keep a river of that kind entirely pure. It is, I understand, impossible to prevent it from flowing into the lake at times, and as a sanitary measure it ought to be made to flow from the lake into the canal during as much of the year as is possible.

Q. In your answer to the question, do you have in mind the possible treatment of the water supply of Chicago by the hypochlorite method?

A. I know that that can be done, either by the hypochlorite method or by filtration.

Q. Isn't that the same question that Cleveland is confronted with today?

A. It is a similar question, I believe.

Q. And Cleveland is a larger city than the Calumet region of Chicago, is it not—has a larger population?

A. Yes.

Q. Will you refer to page 314 of the printed abstract of the testimony, to which reference has already been made this morning? Near the bottom of the page you will find the following statement which was made by Mr. Hering:

"I would say anybody taking a water supply from a river, and I even extend that to the lakes, where there is navigation or commerce, should have its supply filtered before use as a potable supply."

What is your opinion as to the correctness of that statement?

A. It is desirable that practically all water supplies should be filtered. It is a question of cost whether a community can afford to do it. They have to limit themselves on these matters because of the lack of cash. And I also notice that while

he says that "Anybody taking a water supply from a river, and I even extend it here to the lakes, should have its supply filtered," he also says: "I should hardly think it necessary for Chicago to filter the water at the present time. It is always desirable and important if you have the money to pay for it." That quite agrees with my mind.

Q. Speaking of the question of cost, which runs through this whole thing, is it not a fact, both with respect to water supply and sewage disposal, that the City of Chicago has its outfit at a very low expense, compared with other cities of the United States, when you take the two together, water supply and sewage disposal; that it is a cheap plant in both cases, compared with other cities?

A. I don't think that that is the case, because the sewage disposal at Chicago has cost a large sum of money, while in some other cities the question of sewage disposal has been a very limited one.

Q. How about water supply?

A. The water supply is small in Chicago, and all of the lake cities, as compared with cities like New York and Boston which are required to go long distances, and are compelled to build storage reservoirs and aqueducts. But leaving out those two cities, I think other cities have spent much less money for their sewage disposal and water supply combined, as for instance Detroit and Buffalo.

Q. I call your attention to the statement of Mr. Hering on page 316 of this record: "By settling the sewage, the 10,000 cubic feet per second would take care of approximately 4,200,000 people." I will ask you whether in your opinion that is a correct statement on that subject?

A. I don't know, but I should think it might be a reasonable statement.

Q. And it would be proportionately true for smaller populations?

A. Yes, I suppose it would hold good for smaller populations. I take it that this is assuming that the sewage is settled?

Q. Yes. As commerce grows, there is an increasing danger from the sewage which comes from navigation, is there not?

A. It depends on how it is regulated.

Q. In the lakes. What do you mean by "how it is regulated"?

A. Why, it would be entirely feasible, I think, to prevent that danger from navigation, to a very large extent.

Q. But without any such regulation, on the part of the Government, what then?

A. Without regulation, increase of navigation certainly would increase the danger.

Q. Speaking of the effect of the Des Plaines River, is it not your opinion that in order adequately to protect the cities along the Des Plaines and the Illinois and the Mississippi down as far as St. Louis, there should be some treatment of this sewage before it is discharged into the canal, even with a dilution of as high as 3⅓ cubic feet per thousand?

Mr. Austrian: We specifically object to that question, because it is not within the issues in this case.

Q. (Question read.)

A. There is no need of protection to those places, if there is an adequate supply of lake water to properly dilute the sewage. The question of using smaller quantities of lake water and treating the sewage is, to a considerable extent, an economical question as to cost; and, second, to a considerable extent a question of whether one would produce unsatisfactory conditions to other people.

Sewage cannot be treated by any method that I know of, without causing more or less odor and trouble. There is generally less in the dilution method than in any other method with which I am acquainted, when the amount of water is adequate.

Q. I direct your attention to page 322 of the printed abstract of the record, to a statement made by Mr. Hering as follows: "I think it would be safe to discharge the effluent of the sewage of a population of 1,200,000 people into Lake Michigan, after that sewage had been treated by the sprinkling filters, such as were designed and reported by me in the report to the International Waterways Commission in 1906. And today, in view of the comparatively slight cost, I would add the hypochlorite treatment, that is assuming no purification of the water supply." Do you agree with the conclusion of Mr. Hering?

A. I do not, wholly.

Q. In what respect do you not?

A. I do not favor the discharge of the sewage of a great population into a lake from which a water supply is to be taken, in any case.

Q. Without purification of the water supply, I assume?

A. Yes; and even then I would place the intakes of the water supply far from the place where the sewage is turned into the lake, if it were necessary. But it is very much bet-

ter from a sanitary standpoint that neither the sewage nor the effluent should go into the lake.

Q. I want to get your view as an engineer, Mr. Stearns, concerning certain conclusions of the Secretary of War, in connection with this case. He says, first, that this question at bottom is a question of cost. Do you agree with that?

A. To a considerable extent, but not wholly.

Q. He says that: "Other adequate systems of sewage disposal are possible, and are in use throughout the world." Isn't that true?

A. No; other systems which would have to be adequate if there were no means of doing better, but it does not seem to me they are adequate when something better can be done.

Q. He says: "The problem that confronts Chicago is not different in kind, but simply larger and more pressing than that which confronts all of the other cities on the Great Lakes, in which nearly 3,000,000 of this country are living." Is that a correct statement of the situation as you know it?

A. No, it is not, because the other cities on the lakes cannot divert their sewage away from the lake and necessarily have to put it into it, and do the best they can under the circumstances. But Chicago has the natural facilities, and also the works already built and paid for, through which they can do something better and different.

Q. He further says: "The urban population of those cities like that of Chicago is rapidly increasing, and a method of disposing of their sewage which will not injure the potable character of the water of the lakes must sooner or later be found for them all, and that includes Chicago." Isn't that true in your judgment?

A. I do not think it is, because I do not think that method has to be found for Chicago, and all the rest of the cities have got to get along with the best that they can do.

Q. It would have to be found for Chicago in time, even if they were allowed to take 10,000 cubic feet a second?

A. I do not think that is the case, because with 10,000 cubic feet per second they could continually discharge their sewage, or the effluent from sewage disposal works, into the canal, so that it would not go into the lake. So that as long as they can discharge 10,000 cubic feet a second away from the lake, they are not confronted with the same problem that the other cities are.

Q. Up to what limit of population do you think 10,000 cubic feet of water per second would take care of the sewage problem of Chicago, without making it necessary to purify

any of the sewage before it was permitted to be discharged into the lake?

A. To an unlimited extent, because with that quantity of water, as I conceive the case, it would always be possible to keep the sewage and effluent out of the lake.

Q. That is to say in your opinion, with 10,000 cubic feet of water per second taken out of Lake Michigan, a sewage system can be devised which will answer the requirements of Chicago permanently, and as far as it can reasonably be anticipated?

A. Yes. I am only comparing the two things, the one the case of discharging in the future into the lake, and discharging the effluent into the channel, if the city were permitted to take 10,000 cubic feet per second. That is, with 10,000 cubic feet per second, I should say by all means spend all the money that is required to purify the sewage, and put the effluent into the channel, rather than to purify it and put it into the lake. That is, of the two dilemmas the best thing to do would be to purify it and put it into the channel, with that quantity of water.

Q. What would you say if all they were allowed to take was 8,000 cubic feet per second?

Mr. Austrian: When, in the future?

Mr. Wilkerson: Permanently, indefinitely in the future.

A. I should advise that with any quantity of water, which would reverse the Chicago River and prevent it from going into the lake.

Q. And the amount that is necessary to do that is 4,157 cubic feet per second, isn't it?

A. No, it is a good deal more than that.

Q. I want to get your view: You advise the method of handling the sewage which you have indicated, where the permitted diversion from Lake Michigan was sufficient to keep the Chicago River running away from the lake?

A. Yes.

Q. That is the plain Anglo-Saxon of it, isn't it?

A. And the Calumet River to a limited extent.

Q. And the Calumet River to a limited extent?

A. Yes. By "limited" I mean ordinary flow.

Q. Why do you draw a distinction between the Chicago River and the Calumet River in that respect? Why wouldn't you recommend it for the Chicago River, even though the permitted diversion did this under ordinary circumstances?

A. The Chicago River is highly polluted and the sewers in large numbers discharge into it. While I have not inves-

tigated the Calumet region. I know it as a more sparsely settled place in which the sewage can be taken from the river, except to a limited extent. It will be impossible, I think, to keep it entirely clean.

Now, if by means of some moderate amount of diversion from the lake through that river the ordinary flow can be reversed, and by that means the water can be kept flowing from the lake into the river for, say 350 days in the year or 360 days, it is a great gain over having it run into the lake the whole 365 days in the year; and it would not mean, as I believe, a very large quantity of water. I do not know the amount, but the ordinary flow of streams is fairly small, and hence I think that there should be a reversal of that river for as much of the year as is practicable. The physical conditions are such that it cannot be reversed in the time of extreme flood.

Q. That is the Calumet?

A. Yes.

Q. Now I call your attention to another statement made by the former Secretary of War to this effect: "The evidence before me satisfies me that it would be possible in one of several ways to at least so purify the sewage of Chicago as to require very much less water for its dilution than is now required by it in its unpurified condition." In your opinion as an engineer, is that an accurate statement of the situation?

Mr. Austrian: I object to the question, because it appears from the statement read by counsel that it is based on evidence presented to the former Secretary of War.

Mr. Wilkerson: I call your attention to the following statement: "It would be possible in one of several ways to at least so purify the sewage of Chicago as to require very much less water for its dilution than is now required by it in its unpurified condition." Does that state the fact accurately?

A. Not wholly, because it makes no provision for the growth of the city. I suppose that may be intended. But it is true that if the sewage were purified and the effluent turned into the Chicago River, that less would be required per thousand of population than if the crude sewage were turned into the stream.

Q. Then there is this statement to which I call your attention: "A recent report of the Engineer of the Sanitary Commission, October 12, 1911, proposes eventually to use some such method, but proposes to postpone its installation for a

number of years to come, relying upon the present more wasteful method in the meanwhile. It is manifest that so long as the city is permitted to increase the amount of water which it may take from the lakes, there will be a very strong temptation placed upon it to postpone a more scientific and possibly more expensive method of disposing of its sewage." Calling your attention to that statement, I will ask you whether you have given consideration to the report which is there mentioned?

A. I have read it.

Q. Have you considered the estimates of expense which are there made and the conclusions which are reached, and the recommendations which have been made?

A. I have not examined the estimates of expense with any care. In regard to the general recommendations that some purification can be accomplished in the future before turning the sewage into the stream, I have noted that.

Q. And do you agree with the conclusion that there should be some immediate steps taken towards this work of purification?

A. I think that the steps should be taken, as they have been, in getting the information necessary, and if there should be a restriction of the quantity of water from the lake, further steps would have to be taken.

Q. You made some estimates of the cost of providing a new sewerage system for Chicago, the estimates being based upon the comparison with the experience of other cities, as I recall it. Those figures were prepared upon the assumption, were they not, that Chicago did not have the 4,167 cubic feet of water from Lake Michigan, which it is now taking?

A. Yes.

Q. That is to say those figures were prepared on the assumption that it was allowed to take no water out of Lake Michigan?

A. Yes.

Mr. Austrian: You do not mean that.

Mr. Wilkerson: Yes, precisely.

Mr. Austrian: You mean not diverted by means of the Sanitary District. They would have to take some water out of Lake Michigan to run in the sewers.

Mr. Wilkerson: No water for sewage dilution.

Mr. Austrian: By means of a canal such as the Sanitary District Canal.

Mr. Wilkerson: Q. Please state just what the assump-

tion with reference to the taking of water from Lake Michigan was, upon which those figures were prepared?

A. It was assumed that no water would be taken from Lake Michigan for the purpose of diluting the sewage; that is that was assumed in my direct testimony.

Q. But you also assumed that the combined sewers could not be used, but would have to be replaced by a separate system?

A. Yes, that they could not be used for a complete purification of the sewage. I suggested different methods by which the sewage might be treated; and the one to which these estimates refer requires a separate system because it was the intention in that system to purify all of the sewage and not to allow a portion of it to run into the lake or river during storms, as it otherwise would.

Q. And you prepared no estimates, in which there was not the separate system of sewers?

A. Yes, I gave also an estimate for that condition, based upon the Pittsburg, Pennsylvania, estimates, using the same amount per capita.

Q. Just what would you do, Mr. Stearns, as an engineer, supposing you were told it was finally and definitely decided that the maximum amount of water which could be taken out of Lake Michigan was 4,167 cubic feet per second, and you were asked for an opinion as to what Chicago were to do for sewage disposal?

A. That is a question that would be very difficult to answer offhand, but so far as I now know I should favor utilizing any quantity of water for which permission might be given, that is any fairly large quantity of water, and keeping the sewage effluent away from the lake.

Q. You have no doubt the 10,000 cubic feet per second would be ample for that purpose?

A. I believe it is only a question of cost as to the quantity, when one gets up to say 10,000 cubic feet per second.

Mr. Adcock: That is for the Chicago River, you are speaking of?

Mr. Wilkerson: Both the Chicago and the Calumet.

Q. You had in mind the whole Chicago problem?

A. I had the whole thing.

Mr. Austrian: The Sanitary District.

Mr. Wilkerson: And you have no opinion as to whether there is any quantity between 4,167 and 10,000 cubic feet which would answer the requirements?

A. As an offhand judgment, I should say that 10,000 cubic

feet per second was the smallest quantity that was practicable and reasonable, and that it might be and probably would be advisable to furnish more water, having in view the value of the water for this purpose as compared with other purposes in connection with the lakes or the St. Lawrence River.

Q. And having in mind the question of expense?

A. Having in mind all the time the question of expense.

Q. Just one more question so that I may be sure there is no misunderstanding between us: That is when you reach the point where the water in the Chicago River flows away from the lake, then the extent of dilution of that for sewage disposal is one of expense?

A. I should add to that a small quantity of water from the Calumet, to reverse its ordinary flow.

FREDERIC P. STEARNS, recalled for further direct examination by Mr. Adcock and testified as follows:

Q. Mr. Stearns, since you were on the stand the last time, at the request of Mr. Shenehon, the Government's chief expert, I believe you furnished certain evaporation records and rainfall records to him, did you not?

A. I furnished certain records of rainfall and run-off.

Q. Rainfall and run-off?

A. I do not recall that I sent him any evaporation experiments.

Q. Will you state what records you have furnished him and what conclusions you had deduced from the additional records which you have considered since testifying on this subject before?

A. Shall I read these letters to him?

Q. I presume you might just give your data, etc., and your conclusions.

A. I sent him first the average rainfall and the run-off of various streams for a term of years. There was the Wachusett drainage area, in Eastern Massachusetts, where there was 16 years' records, and for the months from June to November, inclusive, of those years, the average rainfall was 22.70 inches. The amount of water running off in the streams collected, what is known as the run-off, was equivalent to a depth of 5.737 inches on the whole drainage area, including the reservoirs.

As a result of those two figures, I found that 25.2 per cent. of the rainfall was represented by the amount running in the

streams. Similar figures were sent for the Sudbury Drainage area, also in Eastern Massachusetts; one 38 year record covering the years 1875 to 1912 inclusive, with an average rainfall of 21.64 inches, an average run-off of 4.110 inches; the ratio being 19 per cent.

The years 1898 to 1912 inclusive are generally excluded from consideration, as the conditions for obtaining an accurate record during those years was less favorable than in previous years. Omiting these years, there is a record for 23 years, 1875 to 1897 inclusive; rainfall 22.608 inches, run-off 4.703 inches; per cent. of run-off 20.8.

I also divided this 23 year period into two parts. In the first 11 years, the rainfall was 21.612 inches, the run-off 3.709, making the per cent. 17.2.

In the second period of 12 years into which the 23 were divided, 1886 to 1897 inclusive, the rainfall was 23.523, run-off 5.615, per cent. 23.9.

Cochituate, Eastern Massachusetts, 50 year record 1863 to 1912 inclusive, rainfall 22.73, run-off 4.98; per cent. represented by run-off 22.0.

The Croton Drainage Area in Southeastern New York, the source of water supply for the City of New York, 32 years record, 1868 to 1899 inclusive, rainfall 25.04 inches, run-off 6.23 inches; per cent. of rainfall represented by run-off 24.8.

12 years record of the same drainage area, 1900 to 1911 inclusive rainfall 25.57 inches run-off 7.01 inches; per cent. of run-off 27.4.

The Perkiomen, in Eastern Pennsylvania, this was one of three streams investigated for a water supply for Philadelphia; record of 13 years 1884 to 1897 inclusive, omitting the year 1889; rainfall 23.26, run-off 5.85, per cent. of run-off 25.1.

Neshaminy Eastern Pennsylvania, 13 years record, 1884 to 1897 inclusive, omitting 1899; rainfall 23.24 run-off 4.69, per cent. of run-off 20.2.

Tohickon, Eastern Pennsylvania, 13 years. 1884 to 1897 inclusive, omitting 1889. Rainfall 24.51, run-off 6.50, per cent. 26.6. The year 1889 was omitted from the record of these three streams, because of an abnormally large rainfall and consequently an abnormally large run-off. The average rainfall at those three places in 1889 was 44.56 inches for the six months under consideration; the average run-off 23.45 inches and the average per cent. of run-off 52.6.

That this rainfall was very abnormal is shown by the fact that the highest rainfall in any other year of the fourteen,

taking an average of the three places, was 27.37 inches as against the average of 44.56 inches the abnormal year.

I furnished also the information as to what the averages would be if that abnormal year was included. It seems to me unnecessary to put that in.

To show that a large rainfall generally results in a large percentage of run-off, and that the run-off is smaller when the rain-fall is lower, certain comparisons were made. First, Wachusett, the highest four years of the record above mentioned, the average rainfall was 54.48 inches, per cent. of run-off, 53.7. This is for the whole year and not for the months from June to November; lowest four years, average rainfall 38.65 inches; per cent. of run-off 44.2. The corresponding figures for other drainage areas: Sudbury, highest six years, rainfall 55.17 inches, per cent. of run-off 52.7; lowest six years, rainfall 36.39 inches, run-off 37.2 per cent. Croton, highest six years, rainfall 59.42, per cent. 53.8. Croton, lowest six years, rainfall 40.59, per cent. 45.7. Perkiomen, highest four years, rainfall 54.28 per cent. 52.6. Perkiomen, lowest four years, rainfall 42.29, per cent. 37.1. Neshaminy, highest four years, rainfall 54.23, per cent. 47.7. Neshaminy, lowest four years, rainfall 41.15, per cent. 44.4. Tohickon, highest four years 56.68, per cent. 58.5. Tohickon, lowest four years, 43.61, per cent. 50.3.

The four years period was selected in some cases and six years in others, in accordance with the length of the record. Where there was a long record, a longer number of years could be chosen for the high and for the low.

The next information sent Professor Shenehon referred to various streams of which I had learned the run-off, as compared with the rainfall in recent years. The first series referred to the discharge of a number of streams in Western Pennsylvania; and in that case I was endeavoring to ascertain the run-off in different months of the year per square mile of drainage area, in connection with investigations for a hydro-electric plant. I studied all of the streams, and got their records in that section of Pennsylvania, and in the Northern part of West Virginia, although I did not use the West Virginia records. And from all of those observations, I determined in accordance with my judgment the run-off of a stream where the hydro-electric power would be located. And what I am giving is not the actual record of any one stream, but my determination made at that time for that purpose. It covers the years 1902 to 1911 inclusive. The rainfall was not the rainfall at a given place, but the average of a

number of places, so as to get the general conditions for that section of Western Pennsylvania.

The streams referred to were in the Allegheny basin, Pennsylvania: Crooked Creek, Black Lick Creek, Kiskiminetas Creek, Allegheny River at Red House, Allegheny River at Kitanning, Clarion Creek, Mahoning Creek, Tionesta Creek, and Broken Straw Creek, Kinzua Creek, and the Quemahoning River. It is not necessary, I think, to mention three other streams in the Monongahela Basin, because they were used to so small an extent.

The final result of this study was that in the year 1902, the rainfall for the six months from June to November inclusive was 23.83 inches, the run-off 8.81 inches and the per cent. of rainfall represented by the run-off 37.0.

The corresponding figures for the succeeding years are:

Years.	Rainfall inches.	Run-off.	Per Cent.
1903	25.77	7.04	27.3
1904	17.84	5.07	28.4
1905	28.05	10.20	36.3
1906	23.24	6.24	26.9
1907	24.04	8.25	34.3
1908	12.74	2.16	17.0
1909	17.42	3.03	17.4
1910	18.00	2.94	16.3
1911	29.27	9.49	32.4

I was engaged by the Manufacturers' Water Company of Johnstown, Pennsylvania, in the building of a dam on the Quemahoning River, and obtained from the company while I was there a series of records of the run-off of the river. That series is as follows:

Years.	Rainfall inches.	Run-off.	Per Cent.
1902	22.10	6.50	29.4
1903	24.80	5.83	23.5
1904	19.79	3.04	15.4
1905	32.18	11.31	35.1
1906	25.80	6.70	26.0

I am Chairman of the Committee on the yields of drainage areas of the New England Water Works Association, and quite a series of reliable records covering the years 1908 to 1911 have been sent in to the Committee, and I have had occasion to study them.

The first three streams of this group are the Esopus Creek, Rondout Creek and Schoharie Creek, which were measured

by the city of New York. They are located in the Catskill Mountains, and one of them at present, and the others later, are to be sources of water supply for the city of New York.

Mr. Wilkerson: This testimony about these records is all subject to our objection and right to call for the original data, just as you called for these Niagara measurements.

Mr. Adcock: I assume so, certainly. I presume that Mr. Shenehon has probably checked them up already.

Mr. Wilkerson: I mean if we want to check them over.

Mr. Adcock: Yes.

The Witness: The discharge of Esopus Creek should be particularly good; that is, in other words, the measurement should be especially accurate, because a weir has been built for measuring the discharge, and the measurements are under the direct control of the engineers engaged upon the construction of the new works for the city of New York.

The drainage area in this case is 239 square miles, and there are at present no reservoirs upon it. The statistics are as follows: (This is for the same six months.)

Years.	Rainfall inches.	Run-off.	Per Cent.
1907	31.92	15.293	47.9
1908	17.89	3.979	22.2
1909	18.82	3.434	18.2
1910	20.47	4.043	19.8
1911	29.21	11.238	38.5

The records for Rondout Creek, which has a drainage area of 105 square miles are:

Years.	Rainfall inches.	Run-off.	Per Cent.
1907	30.19	11.458	38.0
1908	16.52	2.537	15.4
1909	17.59	3.164	18.0
1910	20.43	4.473	21.9
1911	29.68	11.316	38.1

Schoharie Creek, which has a drainage area of 240 square miles, the record is as follows:

Years.	Rainfall inches.	Run-off.	Per Cent.
1907	27.09	13.398	49.5
1908	16.47	2.362	14.3
1909	15.32	2.175	14.2
1910	18.76	4.891	26.1
1911	22.19	7.885	35.5

The next statistics relate to Abbott Run watershed, which

has a drainage area of 26.94 square miles, and is situated in Rhode Island near the Massachusetts boundary.

Years.	Rainfall inches.	Run-off.	Per Cent.
1907	26.10	7.63	29.2
1908	18.40	3.42	18.6
1909	15.75	2.15	13.7
1910	14.26	1.59	11.2
1911	24.83	4.90	19.7
1912	16.10	2.32	14.4

Manhan River drainage area 13 square miles, situated in Massachusetts west of the Connecticut River.

Years.	Rainfall inches.	Run-off.	Per Cent.
1899	18.92	2.92	15.4
1900	18.02	3.26	18.1
1908	15.69	3.77	24.0
1909	17.00	3.18	18.7
1910	19.23	4.09	21.3
1911	31.09	9.88	31.8

Tillotson Brook drainage area 5.84 square miles, situated near the Manhan River.

Years.	Rainfall inches.	Run-off.	Per Cent.
1908	16.88	4.12	24.4
1909	18.48	3.67	19.9
1910	19.16	4.05	21.1
1911	33.40	7.86	23.5

In all of the foregoing records where there are reservoirs for water supply, the measurement does not take the quantity of water that runs in each month from the reservoir, because that would be a nearly uniform quantity, on account of the water stored in the winter and spring for use in the summer; but the effect of storage, so far as it relates to the quantity of storage, is eliminated by the computations so that they represent the natural flow of the stream with the exception of the evaporation from the surface of the reservoirs; and no correction is made for that.

There is one other record of the Merrimack River at Lawrence, Massachusetts, which has a drainage area of 4452 square miles. In this case the effect of storage reservoirs could not be eliminated and hence the run-off during the summer months, during the six months in question, is somewhat greater than the natural flow of the stream, as there are quite a large number of mill reservoirs, and one lake of 36 square

miles upon it used to store water and let it down in the summer. It would affect the results, so there should be a correction for that. In other words, the per cent. of run-off should be somewhat less than the figures shown by the records.

Years.	Rainfall inches.	Run-off.	Per Cent.
1908	13.96	3.611	25.4
1909	15.99	3.339	20.9
1910	16.36	3.488	.21.3
1911	21.98	4.015	18.3

In a subsequent letter to Professor Shenehon, dated October 3rd, I sent him the details for the six months of each year for the rivers Perkiomen, Neshaminy and Tohickon, where before I had given only the average results; and these rivers are shown in the following tables:

Perkiomen.

Years.	Rainfall. inches.	Run-off.
1884	23.07	5.66
1885	19.32	4.06
1886	20.76	5.37
1887	23.96	5.71
1888	26.60	9.57
1890	24.66	7.62
1891	26.47	5.94
1892	20.39	5.04
1893	22.38	5.15
1894	24.17	7.23
1895	17.13	2.07
1896	29.67	7.02
1897	23.76	5.34

Neshaminy.

1884	20.76	2.30
1885	21.47	2.81
1886	20.27	2.53
1887	26.85	5.47
1888	26.01	7.03
1890	24.51	5.48
1891	23.98	4.91
1892	21.71	3.25
1893	23.28	5.44
1894	25.40	7.94
1895	17.62	2.31
1896	23.45	5.06
1897	26.76	8.61

Years.	Tohickon. Rainfall. inches.	Run-off.
1884	25.49	7.88
1885	21.31	4.48
1886	20.15	4.31
1887	25.90	5.71
1888	29.00	11.83
1890	25.69	7.99
1891	26.93	7.02
1892	21.87	4.99
1893	26.13	6.16
1894	24.58	8.95
1895	19.08	1.74
1896	26.34	7.43
1897	26.10	7.10

I have reached certain conclusions from the records of which copies were sent to Professor Shenehon, and which have just been referred to. And before giving the results I may recall the past testimony. In last March, referring to tables A to G, of Stearns' Exhibit Number 1, I stated on page 1256 that I assumed on the basis of past experience that during the months from June to November inclusive 21 per cent. of the rainfall upon the land surface which forms the local drainage area of Lake Ontario would find its way into the lake, through streams or by percolation. The corresponding figure for Lakes Erie and St. Clair (See page 1262) is 20 per cent.

At the time tables A to G were made up in New York, I had to use my best judgment as to the percentages which should be used, because statistics of run-off were not available at that time; but I stated (See page 1257) that the per cent. was based on my memory and that "I could furnish, if necessary, a large amount of material bearing upon that point." And it is this material that has just been entered in the record.

I also stated (Pages 328 and 329 top paging, 1274 and 1275 bottom paging) that it was not necessary to determine the per cent. of run-off with great accuracy, in order to obtain a substantially accurate ultimate result.

As an illustration of the last statement, I testified on page 1275 to the effect that an error of 14 per cent. in determining the run-off from the drainage area of Lake Ontaria would result in an error of only 1 per cent. of the whole quantity of water discharging into and from the lake.

The rainfall and the per cent. of run-off that has been given in these records shows a wide variation; but is a vari-

ation in accordance with the law that the larger the rainfall, the larger will be the per cent. of run-off. And in order to apply those results to Lakes Erie and St. Clair, and to Lake Ontario, it is necessary to ascertain as well as can be from those records, what the run-off would be with the rainfall upon the drainage areas of the lakes under consideration. The average rainfall on the drainage areas of Erie and St. Clair, including the lakes, during the six months under consideration, as taken from the table in the report of the Chief of Engineers for 1903, Part 4, Appendix FFF, Page 2879, is 17.47 inches; on the drainage area of Lake Ontario, including the lake, 19.97 inches.

Where there is a record covering a series of years with high rainfall and with low rainfall, they can be divided into two groups, and I have divided them in each case where the rainfall is 22 inches, with one exception, where I made the dividing line 22.1 inches, as that gave me two observations in the lower group where otherwise I should have had only one.

As an illustration, I took the ten year records of streams in Western Pennsylvania, and there was six years in which the rainfall was more than 22 inches. Averaging these years of what I wil call high rainfall and also the run-off, I obtained rainfall 25.70 run-off 8.34, per cent. 32.4. For the four years when the rainfall was less than 22 inches, I obtained as an average rainfall 16.50, run-off 3.30, per cent. 20. This gives the run-off in per cent. corresponding to two rates of rainfall, and it is only a matter of simple proportion to deduce the per cent. of run-off for other rainfalls.

The result of such simple computations shows that upon the basis of the ten year records referred to, the per cent. of run-off for 17.47 inches, which is the rainfall for Erie and St. Clair would be 21.3 and for the Lake Ontario rainfall, of 19.97 inches, the deduced per cent. of run-off would be 24.8.

Treating each of the other records which I have given, in the same way, with one exception, I obtained results as follows:

Name of stream.	No. of years covered by records.	Deduced per cent. of run-off. Lake Erie and St. Clair.	Lake Ontario.
Western Penn. streams	10	21.3	24.8
Quemahoning River, Pa.	5	19.7	21.9
Esopus Creek, N, Y.	5	16.8	21.9
Rondout Creek, N. Y.	5	17.5	21.6
Schoharie Creek, N. Y.	5	20.6	28.1
Abbott Run, R. I.	6	16.1	18.8
Manhan River, Mass.	6	19.0	21.4
Tillotson Brook, Mass.	4	21.6	21.9
Perkiomen Creek, Pa.	13	19.5	21.8
Tohickon Creek, Pa.	13	12.8	17.6
Average		18.5	22.0

The above tabulation does not include the records of certain streams, for these reasons: The Wachusett, Sudbury, Cochituate and Croton Rivers were excluded because the storage reservoirs upon them cover so large an area that the per cent. of run-off during the six months under consideration would be less on account of the evaporation from the large water surfaces than from drainage areas which did not have large reservoirs upon them, making the results somewhat inapplicable to such drainage areas as those of Lake Ontario, and Lakes Erie and St. Clair. The difference is only small, and if allowance were made for evaporation from the reservoirs the results would coincide very closely; but there is considerable labor in making the computations for evaporation, and I did not attempt to do it. I know that they confirm the results obtained from the others.

The records of the Merrimack River were excluded because the discharge of the stream is augmented by water drawn from storage reservoirs as I have already described, and consequently it would be slightly too large. But still it confirms the others within a small percentage.

The Neshaminy Creek, Pennsylvania, was excluded because the results differed greatly from those obtained from the ten sources referred to in the table. It seems probable that those results are in error by reason of underground percolation during the drier portions of the year. It is often the case where streams are rather steep and the ground is gravelly or

sandy, that a part of the flow passes underground and would not be measured at the weir erected for the purpose of measuring flow. I do not know whether that is the case here or not, but it was far away from the others, the deduced percentages for Lakes Erie and St. Clair being 5.4, and for Lake Ontario 11.9.

I have stated in my testimony that I adopted originally 20 per cent. as the run-off from the drainage areas of Lakes Erie and St. Clair; and I should now, with this information before me, adopt 18.5 per cent., and for Ontario I should now adopt 22 per cent. instead of 21.

These changes would affect the final result only a fraction of 1 per cent.

Mr. Wilkerson: You mean 1 per cent. of the run-off?

A. No, 1 per cent. of the total result in the flow of the Niagara and St. Lawrence Rivers. I said less than 1 per cent.

Mr. Adcock: Have you considered any records of evaporation, to determine the amount of evaporation upon the lake surfaces of Erie and Ontario and St. Clair?

A. I have.

Q. State what records you have considered, and the conclusions that you have reached.

Adjourned to Wednesday October 15, 9:30 A. M.

Wednesday October 15, 9:30 A. M.

Met pursuant to adjournment.

Mr. Shenehon: In a statement made yesterday, in response to a suggestion that the equation used by me in computing the discharge of Niagara River in U. S. Exhibit M, reference was made to a 1912 Report. This is the Report of Mr. Sherman Moore, Assistant Engineer; and it was stated that a blue print showing the curves of discharge for the condition of the outflow by the St. Lawrence River prior to the building of the Gut Dam in 1903 and after that time had been made. It was also stated that the annual report of the Chief of Engineers for 1912 showed the equation indicated on the blue print for that period of time after the building of the Gut Dam.

On reference to the annual report of the Chief of Engineers, Appendix FFF referring to the Northern and Northwestern Lakes, on page 3547, I find that the equation given, the second

one from the bottom, has a broken type where the exponent should be outside the parenthesis. Three halves is the power indicated, or the exponent indicated.

In the last equation, St. Lawrence River for 1908 to 1911, the exponent does not appear at all. It should have a three halves exponent outside the parenthesis.

Mr. Williams: The St. Clair should have an exponent also, one half.

Mr. Shenehon: No reference was made to that.

Mr. Williams: I will make the statement from the authority of Mr. F. G. Ray, principal assistant engineer United States Lake Survey, for the Lake St. Clair, for the river, the last quantity in the parenthesis, Ft. Gratiot minus St. Clair Flats should have an exponent of one half.

Mr. Shenehon: You had these corrections.

Mr. Williams: I had the corrections, yes. I would like to make a request now for a copy of that sheet; also I would like a copy of Mr. Moore's full report, as the observations were only part of them published, I believe. His observations in 1912 have not yet been printed. I find those of 1908 and 1909.

Mr. Shenehon: I believe the report is unpublished.

Mr. Williams: We would like a copy of that report.

FREDERIC P. STEARNS, Resumed.

(Last question read)

The Witness: I testified in this case as to the probable amount of evaporation from Lakes Erie and Ontario during the months from June to November inclusive; the testimony being based, as stated, on my previous studies of the temperature of small lakes and reservoirs and of evaporation. The testimony was to this effect: That the temperature of water is the most important item affecting the amount of evaporation. (See page 1236.) And that there were other features affecting the amount of evaporation, namely the relative humidity of the air and the force of the wind.

Subsequently attention was called on page 1251, to the fact that the items, relative humidity and force of wind had no importance in a comparison between the evaporation from Lakes Erie and Ontario, because both of these features were so nearly the same at the two lakes, leaving only the temperature of the water as the important item affecting the amount of evaporation from these lakes.

My testimony also stated (see page 1237) that the temperature of water depended only to a very limited extent upon the depth of the reservoir, in reservoirs of the size with which I was especially acquainted. But on page 1260, the testimony states that I had not taken into account the difference in the depths of Lakes Erie and Ontario in connection with the amount of evaporation, because it did not seem to me that it was material, for the reason that the temperature of water in cases where I had knowledge of such temperature followed closely the temperature of the air.

On page 1254, I described the method of obtaining the probable evaporation from Lake Ontario for the six months from June to November inclusive, and adopted as the total amount of evaporation for those months from that lake 21.8 inches.

On page 1259, I adopted as the corresponding evaporation from Lakes Erie and St. Clair 24.4 inches. All of these determinations were made at a time when I did not have access to the records of the temperature of the water of these lakes, and also I did not have available evaporation records which are now available.

In the line of new information, I found extended records of evaporation at the Mt. Hope Reservoir of the Rochester, New York, Water Works. The experiments for the warmer months cover 17 years from 1891 to 1907, and for the colder months 12 years from 1896 to 1907. The more trustworthy experiments appear to be those made in a tub floating in a reservoir and the corresponding mean temperature of the water in the floating tub is given. The mean humidity of the air during these years was 73.8 per cent., or substantially the same as at Lakes Erie and Ontario. The average velocity of the wind in the last two years at the evaporation tub, taken 4 feet 5 inches above the water surface, was 6.2 miles per hour, or about 59 per cent. of the average velocity of the wind at Lakes Erie and Ontario.

An examination of these records shows, as do other records of evaporation, that with a given temperature of water there is more evaporation during the months when the temperature is increasing; that is, during the months of April, May and June, than in the months when the temperature is decreasing; as for instance, August, September and October. Upon the basis of these records, the number of inches of evaporation corresponding to a given water temperature may be computed with sufficient exactness for the present purposes by subtracting 24.5 degrees from the water temperature and multiplying

the remainder by .103. This rule may be expressed by the formula E=T—24.5×.103, in which E equals evaporation and T, the temperature of the water in degrees Fahrenheit.

A copy of these records and a comparison with the evaporation as computed by the above formula is shown in the following table:

Rochester Evaporation Records.

Month.	Temperature of water (Degrees Fahrenheit)	Evaporation as recorded (inches)	Computed evaporation (inches)	Difference of computed from observed evaporation (inches)
Jan.	32.8	0.75	0.86	+0.11
Feb.	32.4	0.79	0.81	+0.02
Mar.	36.4	1.44	1.23	—0.21
Apr.	46.5	2.61	2.27	—0.34
May	58.6	3.74	3.51	—0.23
June	67.9	4.52	4.47	—0.05
July	72.3	5.14	4.92	—0.22
Aug.	71.3	4.86	4.82	—0.04
Sept.	65.6	3.86	4.23	+0.37
Oct.	53.6	2.74	3.00	+0.26
Nov.	42.8	1.52	1.89	+0.37
Dec.	34.3	1.16	1.01	—0.15
Total and averages,	51.2	33.13	33.02	—0.11

It may be noted that Table 62 of Williams' Exhibit 34 is a transcript of the published records of the evaporation experiments at Mt. Hope Reservoir, Rochester.

As already stated, and as shown by the table submitted by me, a given water temperature causes more evaporation when the temperature is rising than when it is falling. It is therefore feasible to deduce a somewhat different rule or formula, which will express better than the one already given the evaporation during the months from June to November inclusive. This formula is: E=T—30×.118.

Other evaporation experiments have been made at the University of North Dakota, and the results for the years 1905 to 1911 inclusive, are given in the Water Supply Papers of the United States Geological Survey, of the following numbers and pages: Number 245, pages 66 and 67, number 265 page 74, number 285 page 74, number 305, page 53.

In this case, as at Rochester, the evaporation of water from a floating tank was determined. The tank was in the center of a raft in a pool on a small stream which runs through the campus of the University of North Dakota, immediately west of Grand Forks and two miles west of the Minnesota boundary. The water temperature is the temperature observed at about six P. M. The observations are reasonably complete only for the months from May to October, inclusive.

A formula has been deduced to cover the amounts from June to November, inclusive. It is $E = T - 27 \times .114$. A copy of the records from June to October inclusive, and a comparison with the evaporation as computed by the above formula is shown in the following table:

University of North Dakota Evaporation Records.

Month.	Temperature of water. (Degrees F.)	Evaporation as recorded. (Inches)	Computed evaporation. (Inches)	Difference of computed from observed evaporation. (Inches)
June	67.0	4.51	4.56	+0.05
July	73.0	5.82	5.24	—0.58
Aug.	69.6	4.60	4.86	+0.16
Sept.	59.5	3.51	3.70	+0.19
Oct.	45.0	1.92	2.05	+0.13
Totals and averages,	62.8	20.36	20.41	+0.05

The evaporation experiments at Chestnut Hill near Boston have already been described in my testimony. The formula representing the results of these experiments for the whole year is $E = T - 22 \times .110$.

The recorded evaporation for all months of the year and a comparison with the evaporation as computed by the above formula is shown in the following table:

Chestnut Hill Evaporation Records.

Month.	Temperature of water (Degrees F.)	Evaporation as recorded. (Inches)	Computed evaporation (Inches)	Difference of computed from observed evaporation. (Inches)
Jan.	32.0	0.96	1.10	+0.14
Feb.	32.0	1.05	1.10	+0.05
Mar.	36.7	1.70	1.62	—0.08
Apr.	44.3	2.97	2.45	—0.52
May	57.7	4.46	3.93	—0.53
June	67.9	5.54	5.05	—0.49
July	73.7	5.98	5.69	—0.29
Aug.	72.9	5.50	5.60	+0.10
Sept.	66.9	4.12	4.94	+0.82
Oct.	55.2	3.16	3.65	+0.49
Nov.	44.1	2.25	2.43	+0.18
Dec.	36.1	1.51	1.55	+0.04
Totals and averages,	51.6	39.20	39.11	—0.09

To apply these various formulas so as to determine the evaporation from Lakes Erie and Ontario for the months June to November inclusive, it is necessary to know the temperature of the surface water of these lakes. Such records in the cases of Lakes St. Clair and Erie have been kept by the United States Lake Survey and at the Water Works Pumping Stations at Detroit and Cleveland; on Lake Ontario they were kept by the United States Lake Survey. I have here a table giving the average temperatures of surface waters of the Lakes under consideration for the months from June to November inclusive, in degrees Fahrenheit. It is as follows:

Average Temperatures of Surface Waters of Lakes for the Months from June to November, inclusive, in Degrees Fahrenheit.

Lake.	Authority.	Mean Temperature.
St. Clair	United States Lake Survey records, 1905-06. Williams' Table LXI c, sheet 4, and diagram furnished by F. C. Shenehon.	61.9
St. Clair	Detroit Water Works Pumping Station, July, 1907, to June, 1910. Williams' Table LXIb, Sheet 3.	61.7
	Average of above, adopted as temperature of Lake St. Clair.	61.8
Erie	United States Lake Survey records, as given in Williams' Table LXIc, Sheet 5, and diagram furnished by F. C. Shenehon:—	
	Toledo Harbor Light Station, 1905-07.	63.4
	Southeast Shoal Light Vessel, 1905-1906.	64.6
	Horse Shoe Reef Light Station 1905-08.	62.1
Erie	Temperature by United States Lake Survey Records, average of all observations	63.1
Erie	Cleveland Water Works Pumping Station 1907-11, Williams' Table LXIV, Sheet 4.	63.0
Erie	Cleveland Water Works Pumping Station, 1906-10; taken from Annual Reports of Water Works Division, Department of Public Service, Cleveland, by F. P. Stearns.	63.2
	Adopted as average mean temperature of Lake Erie.	63.1
Ontario	United States Lake Survey Records, 1905-06.	
	Williams' Table LXIc, Sheet 6, and diagram furnished by F. C. Shenehon.	
	Charlotte Light Station, omitting the observations in July and August, 1906, because of their great variation from observations at the Galloo Island Light Station and from the usual temperatures during these months.	59.8
	Galloo Island Light Station.	60.4
	Average temperature of Lake Ontario by United States Lake Survey records.	60.1

By giving due weight to the much larger size of Lake Erie as compared with Lake St. Clair, the mean temperature of the water of Lakes St. Clair and Erie combined during the months from June to November inclusive is 63.0 degrees. The mean temperature of Lake Ontario during these months is, as above stated, 60.1 degrees. With these temperatures and the formulas for evaporation already given, it is feasible to compute the number of inches of evaporation from each of these lakes during these months, and this is done in the following table:

Evaporation in Inches, June to November, Inclusive, from Lakes St. Clair and Erie and Lake Ontario, by the Various Formulas Already Given.

Formula based on	Computed evaporation from Lakes Erie and St. Clair.	Computed evaporation from Lake Ontario.	Difference.
Rochester records for whole year ($E=T-24.5\times.103$)	23.8	22.0	1.8
Rochester records June to Nov., ($E=T-30\times.118$)	23.4	21.3	2.1
University, North Dakota records, June to Oct., ($E=T-27\times.114$)	24.6	22.6	2.0
Chestnut Hill records for whole year, ($E=T-22\times.110$)	27.1	25.1	2.0

All of the comparisons given in the tables show that the excess of evaporation from Lakes Erie and St. Clair over the evaporation from Lake Ontario during the six months under consideration is substantially two inches. In my previous testimony, I had adopted 24.4 inches as the evaporation from Lakes Erie and St. Clair during these six months and 21.8 inches as the evaporation from Lake Ontario for the same period, making the difference between the two 2.6 inches.

On the basis of the new determinations, and taking into account the greater applicability of the Rochester records on account of the location of Rochester upon the drainage area of Lake Ontario, I have no reason to change the amount of evaporation previously adopted, namely 21.8 inches. With the added information now available, I should adopt for the

evaporation from Lake Erie 23.8 inches instead of 24.4 inches, as stated in my previous testimony. It is not certain that these are the exact amounts of evaporation from a Great Lake, because there may be a greater humidity of the air immediately over a great lake than over the small bodies of water where the experiments have been made, but whatever this effect is, it is the same for each of the lakes. All of them are subject to that condition of the greater humidity of the air immediately over the lake.

On the other hand, large lake surfaces are very much disturbed by waves caused by wind and oftentimes spray is thrown up into the air, thereby increasing the evaporation; and it may be that the effect of waves in increasing the evaporation offsets the greater humidity. The point I wish to make clear is that neither of these causes has any material effect upon the relative amount of evaporation from the two lakes.

Q. Now from your examination of the records of evaporation, which you mentioned and per cent. of run-off, have you reached any conclusion from these new records which would change your previous deductions? If you have state what the conclusions are?

A. I have reached conclusions which I will explain, and they do not change the final results.

Q. That is the final results as stated in the tables in your testimony that you gave in New York?

A. Yes.

Q. In March, I think that was?

A. Yes.

Q. Is there anything you would like to say in explaining the results of these new records?

A. Yes. Slight changes have been made both in the percentage of run-off and in the evaporation from Lake Erie. The change in the percentage of run-off from Lakes Erie and St. Clair amounts to 1200 cubic feet per second, but the change in the evaporation off-sets this 1200 cubic feet to the extent of 900 cubic feet, leaving a net decrease in the local supply to Lakes Erie and St. Clair, during the years under consideration, of 300 cubic feet per second.

According to my former testimony, the difference between the discharge of the Niagara as deduced from the St. Clair measurements, and from measurements made at Niagara was 20,700 cubic feet per second, which should be diminished by the 300, leaving 20,400 cubic feet per second.

The correction due to the change in the per cent. of run-off into Lake Ontario required a correction of 750 cubic feet per second, and reduced a discrepancy formerly estimated as 16,230 cubic feet per second to 15,480 cubic feet per second.

The average of these two corrected results is 15,480 plus 20,400, divided by 2, equals 17,940 cubic feet per second as the present amount of the discrepancy.

My former testimony made the amount 18,465 cubic feet per second, which I called in round numbers 18,000 cubic feet per second, and that is almost precisely the amount now determined, so that the former testimony does not require correction.

Recess to 1:30 P. M.

After recess 1:30 P. M.

FREDERIC P. STEARNS:

Direct Examination Resumed.

Mr. Adcock: Q. Mr. Stearns, I show you four charts which are marked Charts 1, 2, 3 and 4, respectively, and ask that they be marked Stearns' Exhibit 2; (chart so marked) also table which may be marked Stearns' Exhibit 3 (table so marked); and ask you to explain these charts and the table; how they have been prepared by you; also to explain what they show.

A. Chart number 1 of Stearns' Exhibit 2 is a plotting of the figures contained in Stearns' Exhibit Number 1, Table C. On the chart there is a scale, on the left, which shows the elevation of Lake Erie, the Buffalo gage, and the elevations are taken from the report of the International Waterways Commission on the Regulation of Lake Erie for 1910.

Q. That is the elevation as shown by the International Waterways Commission report?

A. Yes.

Q. Why did you chose those elevations in preference to the Lake Survey elevations?

A. They were taken in the first instance as being the most convenient elevations, and in view of the statement made here yesterday by the Government's Chief Expert, Mr. Shenehon, a comparison was made between the heights at Cleveland and at Buffalo, using both the records of the International Waterways Commission, and the United States Lake Survey. This

is for the years from 1890 to 1907. At Cleveland, the two records are practically identical. At Buffalo, from 1890 to 1898, the records of the International Waterways Commission are .1 foot lower than the records of the United States Lake Survey. And it is stated in the report of the International Waterways Commission above referred to, page 94, that their records were derived from the United States Lake Survey tables by subtracting .1 of a foot from the records there given.

Comparing the results given in the report of the International Waterways Commission of Cleveland and Buffalo, the lake elevations at Buffalo from 1890 to 1898 are .083 higher than at Cleveland. In the remaining years, from 1899 to 1907, a corresponding comparison shows that the Buffalo gage is .056 higher than Cleveland. If instead of taking the International Waterways Commission information at Buffalo, the United States Lake Survey information had been taken for the years 1890 to 1898, the difference would have been 0.183, in the same direction as the other. It will be seen from these statements that using the results of the International Waterways Commission makes the relations between the gages at Buffalo and Cleveland for the period 1890 to 1898 much more consistent with the relations in the later period. These are all annual means. During the later period, a self recording gage was used at Buffalo.

Q. That was during the time when they more closely agreed, is that correct?

A. Yes.

Q. Then in your opinion the International Waterways Commission acted properly in making the correction for the preceding period?

A. That is my judgment.

To resume the statement with regard to Chart number 1, the scale at the bottom shows the discharge at Niagara in cubic feet per second. On this diagram has been plotted the deduced Niagara discharge given in Table C of Stearns' Exhibit number 1; and a straight line has been drawn to represent those deduced discharges. This line was obtained mathematically by the principle of centers of gravity. That line shows an increment of 36,580 cubic feet per second.

There is also shown upon the same diagram Complainant's equations for the Niagara discharge at the Bridge Section and the Open Section, with only this change: That there has been added to the discharge 2100 cubic feet per second to represent the flow through the Welland and Erie Canals, and this

2100 is the amount adopted by the International Waterways Commission.

Also on the same diagram has been shown the discharge determined by the International Waterways Commission, as given in their report on the regulation of Lake Erie, 1900, the quantities and heights being taken directly from the table. The purpose was to show the degree of agreement between the various discharge curves or equations, based upon the measured discharges at Niagara.

A comparison of the results of these equations, based on measured discharges at Niagara with those deduced shows that there is one point where they agree, at about elevation 571.50. But there is a wide divergence at high levels of the lake, amounting at elevation 574 to substantially 32,000 cubic feet per second.

The diagram shows that with low levels of the lake, those below elevation 571.50, the deduced discharges are less than the discharges based upon actual measurements at Niagara.

The plottings from Table C, of Stearns' Exhibit 1, already referred to, are shown on the chart by small circles and the year is placed against each circle.

Q. That is the discharge is shown for that year and at the elevation?

A. Yes. The circles are plotted with reference to the scales at the left and bottom of the map, and show the discharge corresponding to the given elevation of Lake Erie for that year.

The circles show the results of measurements from June to November inclusive of each year; but by taking shorter periods of time, one can get the results for lower lake elevations than when the average for six months is taken. I am referring to the years 1895 and 1896, when Lake Erie was lower than ever before. During the last three months of 1895, the average elevation of Lake Erie at Buffalo, according to the report of the International Waterways Commission for 1910 was 570.96. Treating the case exactly in the same way that it has been treated for longer periods, I obtained these results: The St. Lawrence discharge, International Waterways basis for those three months average 171,000 cubic feet per second. The rainfall during the three months was 8.89 inches, on the authority of the annual report of the Chief of Engineers for 1903, Appendix FFF, Page 2897, Table XIII.

The evaporation estimated on the basis of the Rochester formula for the six months from June to November inclusive,

already given in testimony today, was 4.86 inches leaving 4.03 inches as the excess of rainfall over evaporation on and from the surface of Lake Ontario. This is equivalent to an average discharge of 8600 cubic feet per second. A run-off of 22 per cent. of the 8.89 inches from the drainage area exclusive of the lake amounts to 14,900 cubic feet per second.

Lake Ontario lowered during this periof 0.42 feet, equivalent to a discharge of 7400 cubic feet per second, making the total local supply and storage during the three months in question 30,900 cubic feet per second. Deducting this from the 171,000 St. Lawrence discharge gives a deduced Niagara discharge of 140,100 cubic feet per second, which is indicated upon the diagram.

The St. Lawrence discharge, by the Complainant's equation, would have been 185,200 cubic feet per second. Deducting the local supply and storage as before would leave the deduced Niagara discharge, based upon the Complainant's equation for the St. Lawrence 154,300. This is also shown upon the chart.

Similar computations were made for the month of November, 1896. The St. Lawrence discharge by the International Waterways equation or tables was 175,400 cubic feet per second. The excess of rainfall over evaporation was equivalent to 5700 cubic feet per second; the run-off 22 per cent. of 2.68 inches of rainfall, 13,500 cubic feet per second; and there was drawn from storage in Lake Ontario 10,100 cubic feet per second, making the total local supply and storage for this month at the rate of 29,300 cubic feet per second; and the deduced Niagara discharge 146,100 cubic feet per second. For this same month of November, 1896, the St. Lawrence discharge by Complainant's equation was 196,900 cubic feet per second. Deducting the total local supply and storage as above, 29,300 cubic feet per second leaves as the deduced Niagara discharge 167,600 cubic feet per second. The surprising feature, when one considers the extremely low lake levels is that the equations, or at least the equation of the International Waterways Commission, gives a larger discharge at Niagara than at the St. Lawrence, reversing the usual rule that the size of a river increases towards its mouth. The figures are, for November, 1896: Niagara discharge 184,200 and St. Lawrence discharge 175,400. And this result is obtained notwithstanding the fact that the streams are all the time flowing into Lake Ontario. The evaporation in such a month as November is almost invariably less than the rainfall, and the

lake was being drawn down so that as the result of the drawing down of the lake, there should have been some flow from the lake out of the St. Lawrence, in addition to what came in from the Niagara and other sources. It seems to show very clearly that the results obtained by local gagings do not conform with what we know, from a common sense view, to be the facts of the case.

Chart number 2 is made up in the same way as number 1, and therefore does not require explanation except as to the source of the deduced discharge plotted upon it. It is based upon the St. Lawrence discharge as before, but in this case the St. Lawrence discharge is that determined by the equations given for 1912, and the Sherman Moore report of 1912; and more especially as shown on the chart entitled "United States Lake Survey, discharge of St. Lawrence River, Compiled under the direction of Lieutenant Colonel C. S. Richie, Corps of Engineers U. S. A., by Sherman Moore, Junior, Engineer, 1912."

Q. You used in connection with that chart the diagram entitled "United States Lake Survey, discharge of St. Lawrence River," referred to as Sherman Moore's Report of 1912, which I ask may be marked for identification Government's Exhibit O.

A. Yes. A line was computed to represent the mean of the deduced discharges, and this shows that the Niagara increment obtained on this basis is 33,800 cubic feet per second. The increment obtained by the plottings on Chart Number 1, was 36,580 cubic feet per second, which averaged with the result just given makes the increment for Niagara based upon the St. Lawrence 35,190 cubic feet per second.

Chart number 3, is drawn upon the same plan as the others, but in this case the basis is the discharge of the St. Clair River.

In deducing the discharge of the Niagara as given on Chart Number 3, the defendant's equation was used for determining the St. Clair discharge, and the number of years was limited to those from 1895 to 1906 inclusive; the earlier years not being used, for the reason that the channel of the St. Clair and Detroit Rivers was smaller in the former years, and it was thought best to go back to 1895, only.

The increment obtained in this case for Niagara was 38,200 cubic feet per second.

Chart Number 4, is precisely the same as Chart Number 3, with the exception that the complainant's equation was used in determining the St. Clair discharge. The increment for

Niagara deduced on this basis is 34,700 cubic feet per second. The Niagara increment obtained by averaging the two deduced from the St. Clair discharges is 36,450 cubic feet per second, in comparison with 35,190 cubic feet per second obtained from the St. Lawrence basis.

If, again, we average these, the average Niagara increment is 35,820 cubic feet per second.

It is worthy of note that this agrees very closely with Niagara increment deduced by Mr. Williams, on the basis of the relative fluctuations of Lakes Erie and Ontario, and the measured discharges at St. Clair and St. Lawrence.

There is one thing to be noted in connection with all four of the charts, namely, that the increment is practically independent of questions of per cent. of rainfall representing the run-off and evaporation, because the results of changes in those features would be to affect the deduced discharges at Niagara, but not to affect the deduced increment. That is the deduced discharges are always much larger than the discharges based on local measurements at Niagara when Lake Erie is high, and less when Lake Erie is low.

Now the questions of run-off and evaporation do not depend upon the height of the lake to any appreciable extent. The lake is of the same size when it is high or low. They depend upon rainfall and evaporation, which, as I say, are independent of the height of the lake. And a tabulation of the local supply, including the effect of evaporation, shows that it is practically independent of the height of the lake.

Stearns' Exhibit 3 is a table made up on the same basis as Government Exhibit M for Identification and differs from it only in that it is extended so as to cover the years from 1883 to 1890 inclusive; and some changes were made in column 5 as the result of using the elevations of Lake Erie at the Buffalo gage, given in the Report of the International Waterways Commission, instead of the elevations of the United States Lake Survey.

Q. Why did you use the additional years, and did not confine yourself to the years which are indicated in Government's Exhibit M for Identification?

A. The information relating to those years seemed to be as good as the others, and it was very important to use them because they represent high stages of the lake. As shown by the charts just described, it is at high stages of the lake that the difference between the deduced discharges and the discharges computed on the actual measurements at Niagara vary

the most. In a long series of years, that is from 1860 to 1912, the average elevation of Lake Erie was 572.79. The average elevation during the period from 1891 to 1906, being the years covered by Government's Exhibit M, was 572.22. That is it was more than half a foot below the average for a long period of years. By including the years back of 1883, the average becomes 572.62, which, even with this inclusion, is .17 less than the average for the long period of years. I will state in reference to these elevations that for convenience they were taken from Williams' Exhibit 34, Table 18, and in that the months from April to November were used to represent the open season. It would not make any change if the months from June to November had been used, in my judgment.

Mr. Williams: I have to state that Mr. Shenehon and myself have examined the plottings of the sections at Wickwire and Oakfield, which have been made upon Williams' Exhibit 12 now in evidence in this case, and that we find them to be correct transcripts of the original plottings in the possession of the Complainants in this case, and that we accept those plottings on the said Williams' Exhibit 12 as representing the position of these discharge measurements and as replacing or avoiding the necessity of introducing a duplicate chart to show the said location.

Mr. Shenehon: Mr. Williams' statement is verified by me.

Cross-Examination by Mr. Wilkerson.

Q. I understand Mr. Stearns that the method which you have followed in your analysis of the question which is here presented, for the purpose of determining whether or not in your opinion the increment deduced for the Niagara River is correct has been to take the discharge measurements for the St. Lawrence River first, and by combining those observations with the run-off into Lake Ontario, and storage in the lake, making an allowance for evaporation, to determine what in your opinion would be the correct increment for the Niagara, assuming the St. Lawrence to be correct. That is your process, is it, the first step of it?

A. Yes.

Q. Then you have taken the discharge measurements for the St. Clair and combining that with an allowance which you think should be made for the run-off and storage, and making an allowance for evaporation, you have determined what in

your opinion the increment of the Niagara should be, assuming the observations on the St. Clair to be correct?

A. Yes.

Q. Now the determination therefore of the run-off becomes a vital part of the problem from your standpoint, does it not?

A. No.

Q Well, it becomes a part of it?

A. It becomes a vital part in connection with the determination of the discharge at Niagara, but not in the determination of the increment.

Q. Well let us take the discharge now. We will come to the increment after a while. Of course to determine what the run-off is, you must have data as to rainfall; that is the data as to rainfall from the basis of the deductions as to run-off?

A. It does of the deductions that I have made myself but not necessarily because if one had the measured run-off that could be used.

Q. I am speaking about your method now.

A. Yes.

Q. You have tried to derive a percentage of run-off and rainfall which is based upon observations with which you have come in contact upon a number of rivers, drainage basins in New England and Pennsylvania?

A. Yes, and New York.

Q. And New York. Some of which you have accepted as applicable to the situation here, and some of which you have rejected for one reason and another?

A. There is one that I rejected on that account, not others.

Q. You rejected only one, did you?

A. There are several that I didn't work up the results for, because it would have required some computations of evaporation, and one, the Merrimack River, that I didn't use because it included some storage water in the discharge. But they were not inapplicable, and the results that I got from them show that they would have agreed very nearly, although I did not make the computations.

Q. This whole situation would be materially changed, would it not if it is the truth, or the fact would turn out to be contrary to your conclusion here that the run-off into Lake Erie is very considerably less than what you have concluded that it is?

A. It might be materially less, and still make very little change in the final results, as I have already testified that a

14 per cent. change in the run-off, in the per cent. of run-off, would only affect the final results 1 per cent. I think that applied to Lake Ontario, as I stated it, but it would be very nearly applicable also to Lake Erie.

Q. Well, if as a matter of fact the run-off into Lake Erie were such that when taken into connection with the evaporation from the surface of the lake, Lake Erie contributed little if anything to the water supply, it would make a very marked difference as to what you have concluded here?

A. If Lake Erie contributed nothing whatever, it would make a marked difference; but that is not conceivable in view of the results obtained on so many drainage areas with which I am acquainted, some of them not far from Lake Erie, or in view of the results obtained when one takes Lake Erie and Ontario together, independent of these other drainage areas.

Q. In the measurements which were made in different drainage areas about which you testified yesterday, how many rain gages were there to the square mile; or rather how many square miles were there to a rain gage? Take some of them, and let us have the benefit of your information on that subject.

A. On the Sudbury Drainage area there are four gages.

Q. How many square miles in the Sudbury area?

A. On 75 square miles. In the Wachusett, there are four rain gages on 120 square miles. Lake Cochituate, there are two rain gages on the drainage area, but others that are so near by that they can be used. That has a drainage area of 19 square miles.

On the Esopus Drainage area of 239 square miles, as nearly as I can recall, there are ten gages. I only state that number from remembering a list that looked to me to be about ten.

On the Rondout Creek, with a drainage area of 105 square miles, they were about in the same proportion to the number of square miles; I think four or five.

Schoharie Creek with 240 square miles, about the same, rather a less number to the number of square miles.

On the streams in Western Pennsylvania, I used the general rainfall as obtained from about 11 stations.

For the Quemahoning Drainage Area, which is about 92 square miles, there was only one upon the drainage area, but the mean rainfall there was determined also from two others, one at Somerset and one at Johnstown, which were some miles beyond the limits, but not more than ten.

Q. Was use made in studies of these drainage areas, about which you have just testified, of any observations made by volunteer observers, or were they all made where the gage readings were taken under the supervision of an engineer?

A. Nearly all of them were under the supervision of engineers on these Water Works water sheds.

At Quemahoning in Pennsylvania, two of them were either United States Weather Bureau Stations or volunteer, Somerset and Johnstown; and in connection with those Western Pennsylvania streams generally, they were all Weather Bureau Stations or volunteer observations, given in the Weather Bureau Reports.

Q. What is the size of the Erie Drainage Basin in square miles, as you have taken it for your computations?

A. The land surface 24,605 square miles, water surface 9,968, total 34,573. That does not include St. Clair.

Q. If you included St. Clair, it would be what?

A. It would add to those figures, for land, 5,961, water, 503 square miles, a total of 6,194 square miles.

Q. What is the area of the Ontario Basin?

A. Land 25,737 square miles, water 7,243 square miles, a total of 32,980.

Q. Do you know how many rain gages were taken in this Erie Basin as the basis of the estimate of the rainfall which has been used on your side of this case?

A. I used the figures given in the report of the Chief of Engineers for 1903, and the diagram contained in that report, which shows the location of the rain gage stations.

Q. The map shows for itself. I was wondering whether you had ever given any thought to the question of about how many square miles was undertaken to be covered by one of these gages?

A. I had not looked upon it in that light; with a large area and a large number of rain gages, as there were in this case, the territory is well represented. There are some portions of the territory where the rain gages do not appear on the map and the—

Q. That is on the Canadian side?

A. On the Canadian side; and the statement is made in the report of the Chief of Engineers as to how they deduced the rainfall for those sections.

Q. It was kind of a speculation from what was on the other side?

A. I think they had other data.

Q. Now in the Erie basin, the Weather Bureau Stations are marked in black dots, as I understand it, so on the whole basin you see only about half a dozen or so stations where the observations were made by scientific observers; the others being reports made by volunteers?

A. There are six within the drainage area and one at Detroit just outside.

Q. And how many in the basin of Lake Onatrio?

A. Three are shown there.

Q. You are familiar with the physical characteristics of these two drainage basins are you?

A. I am somewhat familiar, but there are many parts that I have not visited.

Q. Well with the drainage basins which you used as the basis for your figures expressing the relation of run-off to rainfall, you are familiar with those basins are you?

A. Reasonably so. With some of them I am very familiar.

Q. What kind of streams are they?

A. They covered all kinds. There were three Mountain streams, coming off of the Catskills, with the high points up to elevation 3,000 feet above the sea, if not higher, as nearly as my memory serves me, distinctly mountain streams.

The Merrimack River, not used but still supporting the evidence. It has a drainage area, as stated, of upwards of 4,000 square miles, a very large stream; a part of it is mountainous; a part of it is not.

The Abbott Run watershed, which is one of those stated, and the Cochituate watershed are both low and sandy.

The Croton watershed has a good many hills in it.

Q. That was a high rainfall and sandy land?

A. Not necessarily high rainfall, because there were years of low rainfall as given in the figures presented. One drainage area was only 5 square miles, and yet it gives substantially the same results as the upwards of 4,000 square miles of the Merrimack drainage area.

Q. As to the streams which you considered in Western Pennsylvania, were they in rough country?

A. In a very rough country. That is hilly right there near the Allegheny Mountains and the Laurel Ridge.

Q. What was the condition as to the presence or absence of forests?

A. Why about the average conditions I should say that one finds on almost all of these drainage areas. There are a

good many forests, if you include in that term woods of moderate size.

Q. What was the condition in the Neshaminy basin?

A. I never have visited either of the three basins near Philadelphia, but the gagings were started when they thought of taking those sources for water supply.

Q. Why was it you threw out Neshaminy?

A. Because the results were entirely out of accord with any of the other ten than I mentioned specifically, and out of accord with the results that would be obtained from the records of the Croton, Wachusett, Sudbury, Cochituate and other sources which I did not use.

Q. Do you know whether or not the results in the Neshaminy basin could or could not be accounted for by reason of the physical condition of the country?

A. I believe that it could not be accounted for on that basis for this reason, that taking the whole year and not part of it, during the summer time, the run-off from the Neshaminy averages for a series of years 48.5 per cent. of the Perkiomen, which is near it, 49.2; and of the Tohickon, also near it, 57.6. That is it does not show any abnormal conditions when the year is taken as a whole. But in taking the driest six months when the flow would be very small compared with the whole year, the results were not so consistent and the record showed that if one had tried to deduce from the Neshaminy the run-off corresponding to a rainfall a little less than that on Lake Erie, the run-off would have been Zero.

Q. That is to say you get about the same kind of result from that river as you would have had if you studied the rivers in the Lake Erie basin?

A. Not in the least. There is clear evidence, as it seemed to me, that was a case where a weir had been placed on the ground, and it measured only a part of the run-off, and when the run-off was very small during the summer season, quite a percentage of water was lost from the measurement by running underground. You see that with a higher flow during the whole year, that would be unimportant; that is a large per cent. of the low summer flow is a small percentage of the average flow throughout the year.

Q. What rivers in the Lake Erie basin have you studied?

A. I have never given any special study to any of them.

Q. Isn't it a fact that the physical condition of the country, of the drainage basins which you had used as the basis of your computations here are in practically every case which

you have taken entirely different from the condition of the country around Lake Erie, both as to the kind of soil and as to the level condition of the country, and the presence of hills and forests, and the cultivation?

A. I believe they are not materially different in some of those cases, and not nearly as different as the difference between the various water sheds which are included in those estimates. There has been such great variation in the physical characteristics of the various drainage areas included in those estimates, and they agree so well, that it does not seem as if any change that could result from the different conditions at Lake Erie would make a great difference. It would make some.

Q. That is your testimony in this case is based upon your conclusion that the average of the conditions of the water sheds which you have used as the basis for your computation is a situation which is fairly applicable to the Lake Erie basin?

A. It is not the average of the drainage areas. What we found is that with these great differences the results agree, and you could take the one that seems to be most nearly like Lake Erie, or the one that is furthest from it, and get practically the same results.

Q. Are you familiar with a discussion of the relation of rainfall tc run-off, by George W. Rafter, which was printed in 1903, by the Department of the Interior, U. S. Geological Survey, Water Supply and Irrigation, paper number 80?

A. I am not familiar with it but I have seen it and read parts of it.

Q. He states in this discussion of the subject: "There is no general expression giving accurately the relation of rainfall to run-off. The run-off of a stream is influenced by so many complex elements that the data are lacking for final conclusions. Every stream is in effect a law unto itself. And empirical formula however may be made, which will give for some streams approximately the run-off for a series of years." Does that accord with your view on this subject?

A. The statement that no general formula has been arrived at—I don't remember what his words were—is probably true, because the results which are obtained in the Northern States, under the conditions of humidity which exist here would not apply in the least to the conditions of the Southwestern part of the United States, in the arid country where the evaporation is enormous and conditions are absolutely

different from what they are here. But it is not a correct statement as applied to the Northern and Northeastern section of the country, because the coincidence of results, the close agreement of results taken from different places shows that it is not so; that we can derive a formula within a reasonable degree of accuracy.

Q. He states again: "The errors in rainfall measurements are so large that one may safely state that nearly all measurements are merely approximations." You do not agree with that?

A. No. There are many rainfall measurements that are incorrect.

Q. Which ones would be likely to be incorrect?

A. A number of years ago, the Weather Bureau Station in Boston kept the rainfall record on the top of a high building, with the result that it did not coincide with other rain gages in the vicinity, giving only about 2/3 as much rainfall.

Q. It is a well understood fact that where the rain gage is on top of a building, it registers less than a rain gage on the ground, is it not?

A. That is often the case but I do not know that it is certainly the case, if proper precautions are taken. The Weather Bureau record in Boston at the present time agrees well with other records.

Q. It is perfectly obvious that that would be the result, if the wind were blowing when it is raining, isn't it?

A. No, not if precautions were taken to protect the rain gage.

Q. But if those precautions are not taken, then what?

A. If the precautions are not taken, that is true.

Q. Reading from Mr. Rafter, he says again: "The runoff of streams has been generally over estimated. The minimum flow may be as low as from .05 to 0.1 of a cubic foot per square mile per second. Streams issuing from sand plains may show from 0.5 to 0.6 of a cubic foot per square mile per second. Generally speaking, the range will not be outside of from .05 to .5 of a cubic foot per square mile per second." Does that agree with your experience?

A. The question of overestimating the flow of streams depends on whether it is some good strong promoter of a hydroelectric claim, or whether it is an engineer that knows what he is doing.

Q. It is true, of course, that the streams which issue from

sand plains show a higher amount than where there is a different kind of soil, is it not?

A. It is frequently the case, and depends on whether there is storage in those sand plains that maintains the flow in summer. I am assuming now that question is with reference to the summer flow.

Q. Yes.

A. If one takes the whole year, there is comparatively little difference.

Q. He says again: "The extent of forestation seems to have considerable effect on the run-off of streams, catchments with dense forests showing larger run-off for the same rainfall than those which are deforested. Is that in accordance with your view?

A. I have never been able to know which way forestation affected the flow of streams. I have tried to find it out sometimes, but I have not succeeded.

Q. According to the principle which you deduced, as applicable to Lakes Erie and Ontario in this case, what was the run-off from the drainage basin of Lake Erie, expressed in cubic feet per second per square mile for the period from June to November. I do not care to have that figured out to the third decimal point, but I would like to get approximately what that is; that is the average for the whole period.

A. That would require an averaging of these 20 odd figures.

Q. Pick out a year that looks like an average year, and see what it is?

A. All right, I will take the year 1897 when the rainfall was 17.45 inches, as being nearly an average; 18.5 per cent. of this quantity equals 0.475 cubic feet per second per square mile.

Q. That is for that one year?

A. For that year, which represents nearly an average. If that were a direct average, it would be the average of the whole period.

Q. We can easily get the exact figure by averaging all of the years?

A. Yes.

Q. But the year which you took, which is pretty nearly an average year, it is a little less than half a foot?

A. Yes.

Q. Now let me direct your attention to Williams' Exhibit number 34, table LIXe, Sheets 1, 2, 3, 4, 5, 6 and 7. Let us

take the Maumee River, and see what the actual observations on that river show for the months from June to November, with respect to the run-off in cubic feet per second per square mile. That is one of the largest rivers, as I understand it, that flows into Lake Erie. Do you have a table there in which you have that for each river reduced to cubic feet per second per square mile?

A. Not for that period.

Q. I wish you would take the figures presented by the Defendant in this case with reference to the Maumee River, and let us have an idea about what the shows as to the run-off in cubic feet per second per square mile. I direct your attention to Sheet 5, Table LIXe, Williams' Exhibit number 34. If we take the period from June to November for the Maumee River, which is put down here as having a drainage area of 6,111 square miles, for the month of June, the discharge in cubic feet per second is .514, for July .289, for August it is .113, for September .07, for October .04, for November .169, or on the average about .201, which is less than half of the figure obtained by applying your principle. Wouldn't that indicate that the situation of the drainage basin of the Maumee River, during the period from June to November, is such that the ratio which you have deduced cannot be applied?

A. I know nothing about the facts in this case. I have often had occasion to discriminate a great deal in using the records of the flow of streams, but would not wish to testify as to any one without knowing the facts.

Q. I am merely taking the figures that are put in here by the Defendant in this case as representing the flow of this river. Assuming that these figures are correct, and that the mathematical part of the table is correct, it would indicate that there is a situation with respect to the Maumee River that is different from the drainage basins from which you derived the ratio which you have applied to this situation, wouldn't it? I do not ask you to pass upon the correctness of the measurements, or anything of that sort, but I ask you to assume that they are correct?

A. I do not know the rainfall during these years as applied to this case. The run-off varies a great deal on different streams during the months from June to November, as I have shown by these records which I have introduced today.

Q. But it is perfectly obvious, isn't it, that Mr. Williams

gets one result from the measurement of the river itself, and you get a result about twice as large by the application of the ratio based upon experiments in New England and in Pennsylvania.

A. I do not know the results as to that particular river.

Q. They are here. It gives the Maumee River. I understand they are put down on Table LIXe, Sheets four and five, and we are given the figures which show the measured discharge of the Maumee river for the years 1899, 1900, 1901, 1903, 1904, 1905 and 1906; and from that there is deduced the discharge in cubic feet per second per square mile on Lake Erie, that is it is reduced to that. Assuming the figuring is done correctly, that would indicate a much smaller result for that river wouldn't it than your result?

A. My result applied to the drainage area of Lake Erie as a whole. My rainfall applied as a whole to that. I do not know where the Maumee River is nor what the rainfall is.

Q. Suppose that the Maumee River was about 1/4 of the whole drainage basin of the lake, would you think that was entitled to some consideration?

A. It would be, certainly.

Q. It is about 1/4, about 1/5 of the drainage area. Having in mind that the Maumee River, as Mr. Williams has stated, is about 1/5 of the drainage basin, if you measured the Maumee River and got a result of that kind, wouldn't that indicate to you that there was something in the physical condition of that country that made inapplicable this formula based upon New England and Pennsylvania experiments?

A. I should want to know the rainfall of the Maumee River and the character of the gagings, assuming the gagings were right, if that were proved.

Q. I ask you to assume it is all correct, for the purpose of my question you may assume that the gagings are correct and that the computations are correct?

A. Yes, but that does not cover the question of the rainfall in that place. If the rainfall on that drainage area were the same as the average rainfall of Lake Erie and if all those results were correct, and if those years represented the rainfall as represented by the whole 24 years that are included in the tables—

Q. It is a matter of fact isn't it that what data we have with reference to rainfall show that the average rainfall for

the basin of the Maumee River is substantially the average rainfall of the whole Erie basin?

A. I don't know.

Q. Suppose that it should turn out that was the truth?

A. I was answering on that basis, when I was interrupted.

Q. On that basis, what have you to say about it? I will try not to interrupt you again.

(Answer of witness read as follows: "Yes, but that does not cover the question of the rainfall in that place. If the rainfall on that drainage area were the same as the average rainfall of Lake Erie, and if all those results were correct, and if those years represented the rainfall as represented by the whole 24 years that are included in the tables"—) then it would mean much.

Q. Now let us take another record in this basin. Let us take a small river. We have taken a large river, the Maumee; let us take the Sandusky River. That is on Sheet 6; this same table, LIXe?

A. Yes.

Q. And I find the discharge in cubic feet per second per square mile in June .238, July .07, August .185, September .03, October .05 and November .03. Now there we find the same situation, do we not, only more marked than in the case of the Maumee?

A. Yes, but that record, it should be noted, covers two years, and as I remember they were fairly dry years, weren't they?

Mr. Adcock: Q. What years were they?

A. 1899 and 1900.

Mr. Wilkerson: Q. The rainfall for that year on Lakes Erie and St. Clair was 20.06, which appears to be a heavy rainfall?

A. I do not find that figure on my table.

Q. I am referring to your own table B.

A. 1899 was one of those years, and the rainfall was 14.01.

Q. 1900 was the other?

A. 19.50.

Q. That is pretty nearly an average, not much below. Well let us take another one of those rivers. Let us take the Huron River. That has a drainage basin of 757; we have figures there on Table LIXe, sheet 4, for the years 1904, 1905, 1906, 1907 and 1908. The discharge, cubic feet per second per square mile for June is .644, for July .270, for August

.226, for September .214, for October .267, for November .365, making an average of about .331 as I get it. That still shows considerably below your figure, does it not Mr. Stearns?

A. Yes, a little more than 2/3.

Q. A little more than 2/3?

A. 2/3 of the figure.

Q. Now assume for the purpose of your answer to this question, Mr. Stearns, that the study which has been made of practically every river which has been studied in the Erie basin on your side of the case indicates a result materially less than the one which you have stated here as expressing the effect in cubic feet per second per square mile; and assuming that the average of all the rivers which have been studied for all of the years is as stated in Table LIXa, Williams' Exhibit 34, for the period from June to November, that the figure is .252, wouldn't that indicate to you that the data which have been compiled from the observations in New England and Pennsylvania are not applicable to the situation in the Erie basin?

A. It would not without investigation, but even the information from a number of rivers without knowing the accuracy would have some weight.

Q. And in the light of what I have directed your attention to here from Mr. Williams' Exhibit number 34, do you not believe now, having in mind all these things about the uncertainty of rainfall and run-off, that there is more reason to believe that Mr. Williams' figure of .250 is more nearly correct than your figure of .475.

A. I do not. I should still believe that the deductive method was more likely to give correct results than the ordinary measurements such as are contained in the reports of the United States Geological Survey.

Q. And that would be true, even though it would appear that the drainage area covered by the study of these rivers in the Erie basin embraced 1/3 of the whole drainage basin?

A. Yes.

Q. In your opinion?

A. I say that because I have had so much difficulty in getting results that were at all trustworthy from those United States Geological Survey records.

Mr. Adcock: That is, of run-off?

A. Yes.

Mr. Wilkerson: Q. Isn't it a fact this Lake Erie drain-

age basin is a most peculiar one, in that there are practically no rivers that come into it on the Canadian side?

A. I have never examined them.

Q. Just look at the map. I show you here the map of the Lake Erie Drainage Basin (presenting same to witness); just look at the utter absence of rivers that come in on the Canadian side.

A. The map seems to be very much a blank on the Canadian side, this particular one, as far as towns or rivers or railroads or anything else.

Q. It shows the rivers that come in, that is all a mile back on the Canadian side. (Question read as follows: "I show you here the map of the Lake Erie drainage basin (same being Williams' Exhibit 11) look at the utter absence of rivers that come in on the Canadian side" of any size, I mean.

A. The map does not show railroads and other features, and apparently does not show the rivers in a way that one can form any judgment from it.

Q. You have no independent knowledge on the subject?

A. I know that there is a Grand River coming in towards the easterly end of the lake, and the Thames coming into Lake St. Clair; and those are only shown for a very short distance, and do not indicate how much of the territory they cover.

Q. And you have no knowledge about the size of the river?

A. No.

Q. But in the study which you made of this case, did you give any consideration to the difference between the drainage basins of Lake Erie and Lake Ontario, with respect to the size and volume of the rivers which empty into Lake Ontario, as compared with those which flow into Erie?

A. I did not.

Q. Did you take into consideration the fact that the country all around the lake is flat; that it is cultivated; that there is a clay soil, and did you hear it suggested in the course of your study of this situation that during the period from June to November, practically all of the water is absorbed by the soil, and very little of it runs into the lake?

A. That last statement is correct nearly everywhere, that one does not see the water running off much during the months from June to November, unless there are some very heavy rains in the Autumn. I should expect that would apply to Lake Ontario as well as Lake Erie.

Q. Now is it a fact, so far as the records of humidity for Lake Ontario have been studied, they show a very much larger

run-off measured in cubic feet per second per square mile than do those of Erie?

A. I should expect they would show a larger run-off; and they are so shown by my computation.

Q. How much larger do you show it? What is your figure for Lake Ontario, so far as run-off in cubic feet per second per square mile is concerned?

A. I prepared that figure on one occasion, but I don't find it.

Q. It is not very much larger than the one you have given for Erie, is it?

A. It is considerably larger because one is 18½ per cent. of a smaller rainfall, and the other is 22 per cent. of a larger rainfall.

Mr. Shenehon: Those are revised figures?

The Witness: Yes.

Mr. Wilkerson: I direct your attention to the fact that Mr. Williams in his table LIXa, for the months of June and November gives an average run-off of cubic feet per second per square mile for the Ontario basin of .924, which is between three and four times as much as the run-off for Lake Erie. Your figure has no such difference as that, has it?

A. It has not.

Q. As a matter of fact your figure would be, I assume, not much more than 10 per cent. more for Ontario than Erie, would it?

A. Much more than that.

Q. 20 per cent.?

A. The percentage of run-off—

Q I would like to get the figure for Ontario, because the point I am trying to make Mr. Stearns, and I think it is a legitimate one, is that the drainage basins of Erie and Ontario are absolutely different; and that that is shown by the study which has been made of every river that empties into Erie and Ontario.

A. The run-off of Ontario for the whole period from 1883 to 1906 inclusive, by my computations was .637 cubic feet per second per square mile.

Q. Now have you giver any consideration to this table, Table LIXb, sheets 1 to 11, Williams' Exhibit number 34, in which there is a study made on behalf of the Defendant in this case of the run-off from the drainage areas of different rivers which empty into Lake Ontario?

A. No.

Q You have not studied that. Let us take some of those

ivers, without going into the details of the particular river, he summary of it which appears in Table LIXa, is that of un-off in cubic feet per second per square mile for Ontario rom June to November, that it is .924. That is to say the esult of Mr. Williams' study of the rivers themselves which mpty into Lakes Erie and Ontario is to give for Erie a very onsiderably lower figure than your figure, and for Ontario very considerably higher figure?

A. Yes.

Q. You had in mind that you were not willing to accept, as n engineer, the gagings of these different streams without nore specific study of them. You thought the probability as that they were in error?

A. That many gagings are in error. I have no doubt that ome of them are well taken, but I don't know which ones.

Q. As a matter of fact, in a large number of observations f that kind, would you think that some were taken reasonbly accurately, and there were errors in others; that in the umber of records the errors might balance each other; that as been the method you have applied right along in your easoning in this case, has it not?

A. It is not.

Q. Didn't you apply that, as far as rainfall was concerned hen you gave credit to the observations of these volunteer bservers; didn't you have in mind that while one might have nade a mistake in one direction, another would have made a nistake in another direction, so that in the end they would alance up?

A. No. In studying, to take a specific case, the run-off of treams in Western Pennsylvania, I compared carefully the esults at different places, and a great many observations were hrown out as having internal evidence that they were incorect. And the same was true in measuring the flow of streams. took a sheet as much as 18 inches long, and put the flow of ifferent streams side by side, and from that deduced what he flow would be, not by direct averaging, but throwing out hose that were anomalous. As a result, my yearly run-off as less than half of the quantity that had previously been onsidered to be a proper quantity based upon a given stream. he run-off records of that stream were in my judgment at east double what they were really; that is the result given in he tables was double the actual discharge.

Q. Is it not your conclusion, after having your attention irected to the studies of these rivers in the Lake Erie basin nd the Lake Ontario basin, which have been made by Mr.

Williams, that there is reason for the view that there is a greater difference in the condition of the two drainage basins than is indicated by the figures which you yourself have given in this case?

A. I think it very probable that there is. That is I should give weight to measurements, even without examining them; but I would not give the weight that would be indicated by any direct averages, and especially if they covered the drier years.

Q. Is there not as much reason for accepting the data about the measurement of these rivers in the basins of Lake Erie and Ontario in this case as there is for accepting the observations of rainfall in Erie and Ontario?

A. I do not think that that is the case.

Q. Why not?

A. Because in the experience I have had with rainfall, the results have checked from one station to another.

To revert once more to that Western Pennsylvania situation, I drew contours showing the lines of equal rainfall in all Western Pennsylvania, and they were very consistent, seeming to indicate that the rainfall observations were on the whole very well taken.

Q. Suppose these rivers checked very well too?

A. My similar experience with rivers as reported by the United States Geological Survey has been in the line that they did not check, or come anywhere near it.

Q. Now, as bearing on the condition of this Erie basin, I want to read to you something from the testimony of Mr. Williams in this case, and see whether you agree with him, serial pages 988,989:

"The comparisons of run-offs of various streams in Michigan, which I have studied for a number of years, show a quite wide variation in the amount of water—in the percentage of rainfall that appears as run-off; those streams coming from sandy areas giving relatively large run-offs; those streams coming from highly cultivated areas giving small run-offs.

The comparison of the streams in the West, that is, in the Central States with those further East, say in Central New York, where the country is much more precipitous, indicates that the percentage of run-off in the New York streams is considerably greater than in the Michigan and Wisconsin and Illinois streams, by reason of the fact that the rain that falls flows quickly into the streams and is carried off quickly, before it has time to evaporate.

There are all those conditions that have to be taken into account. For example, the run-off from the State of Ohio is noticeable for its smallness relatively to the others. The high cultivation apparently, combined with the character of the soil which is a loam, and with the character of the surface, which is moderately rolling, seems to conduce to a very high evaporation or a very large absorption by plant roots, and subsequent evaporation so that the run-off from the Ohio streams, both those which flow into Lake Erie, and those which flow into the Ohio river is considerably less than is the run-off of those streams that flow into Lake Michigan and Huron, or into Lake Ontario."

A. The question was do I agree with that?

Q. Yes?

A. I have no information as to the Ohio streams, and many others. With regard to the precipitous character of the ground causing a larger run-off during the months from June to November, I think that is very doubtful in view of the measurements of the three streams that come from the Catskill Mountains. I recognize that the flow of those streams is very much larger than the flow of streams coming from low ground, because there is a higher rainfall upon the mountains, much higher than upon the lower ground; but the percentage of run-off as shown by this table which I have presented does not show a larger per cent. of collection. That is it is not because the water runs off more freely that more comes from the mountain stream, but because the elevation causes a greater rainfall and in the drainage area of Ontario there are no high elevations, until one gets to the Eastern part near the Adirondacks. There the conditions should be similar to the conditions in the Catskill Mountains, except that it is further inland, so that the rainfall presumably is less.

Q. I think you said you had not made any study of the volume of the rivers that emptied into Lake Ontario?

A. No.

Q. So that it is a fact is it not that generally speaking your testimony in this case is speculation based upon experiments in New England, New York and Pennsylvania rather than upon a study of the physical condition of the two basins in question?

A. It is not regarded by me as a speculation. It is the application of well defined laws to these basins; and some of the streams from which those laws were deduced are streams

that are just south of Lake Erie, which empty into the tributaries of the Ohio river and finally into the Ohio.

Q. But it is the application of laws deduced from a study of basins which the rivers in the Erie and Ontario basins themselves show are not applicable to those two basins, is it not?

A. I don't know whether they show that or not, without having the information. I did not expect that these various streams like those in the Catskill Mountains would come into line with the general law, but they did.

Q. Your attention has not been directed to this study of the rivers in the Erie and Ontario basin, already in the case, your attention was not directed to it before you prepared, Mr. Stearns

A. I had seen some of the figures and knew while I was making those studies that the run-off from streams as computed by Mr. Williams into Lake Erie was much smaller than the run-off into Lake Ontario. But notwithstanding that knowledge, I did not credit that as being the correct record of the whole of the drainage areas of those lakes.

Q. Do you not think, if we wanted to get real accurate information as to how much water there was running into Lake Erie and Lake Ontario, the place to go to get it would be the records of the rivers that empty into Lake Erie and Ontario themselves, wouldn't that be the best way to do it?

A. That would be valuable for a part of the drainage area. Due allowance should be made for those sections of the drainage area where there were no measurements, and due allowance should be made for the inaccuracies of such measurements.

Q. Now I direct your attention to your Exhibit 1, Table E. I understand in your testimony you have expressed the opinion that during the period from 1889 to '90, the discharging capacity of the St. Clair river was increased by some 24,000 cubic feet per second. If that is true, why shouldn't the figures in column 5 of Table E down to the year 1890 be reduced by 24,000 for each year?

A. I don't find any such statement in Table E.

Q. I am speaking of your general testimony in the case, which I understood you to say has the effect of certain things which change the regimen of the St. Clair river, you were of the opinion that during that period 1889 to 1890 there was such a change in the regimen of the St. Clair river that there

was an increase in its discharging capacity of about 24,000 cubic feet per second?

A. I don't think that is the case. I don't recall such testimony.

Q. I direct your attention to your testimony, page 1307 "Q. Assuming that as stated in your answer to the preceding question, Huron has fluctuated 14 per cent. more in the earlier period, that is from 1860 to 1889, inclusive, than it did from 1891 to 1910, inclusive, what do you say as to whether the discharging capacity of the St. Clair and Detroit rivers was greater or less in the former or in the later period" (that is from 1860 to 1889 and from 1891 to 1910). "A. It was greater. Q. Assuming that the discharge of the St. Clair river was 197,600 cubic feet per second at certain stage of lake during the latter period (that is 1891 to 1910) that is stage of Huron, what would have been the discharge of the St. Clair river at the same stage during the earlier period?

A. I cannot give a definite amount, but on the basis that the discharge at a given stage increases at least as rapidly as the increment increases, and since the increment varies inversely as the fluctuations, it would not have been more than 87½ per cent. of 197,600 cubic feet per second, equal to 172,-900 cubic feet per second.

Q. What would then be the difference between that and the discharge in the former years?

A. Not less than 24,700 cubic feet per second."

Q. Assume that is true, why shouldn't those figures in column 6 prior to the year 1891 be reduced by 24,700?

A. That is column 6 of Table E?

Q. Table E. I mean column 5 or 6?

A. This was an attempt to make a comparison between a deduced St. Clair discharge, and the discharge determined by the Complainant's equation.

Q. But the complainant's equation was derived from observations all made after 1891, was it not?

A. Yes. But notwithstanding that fact, if the channel had not changed its size or flowing capacity, then the complainant's equation would have applied to the year 1883; for instance the first one in the table.

Q. Yes.

A. But the fact that it did not apply shows that the channel has increased in size.

Q. That is true, but here you are comparing the St. Clair river discharges as deduced from the Niagara river with the

computed discharge. Now for the purpose of showing that the Niagara readings are out of line with the St. Clair readings, you have a St. Clair discharge which is deduced by the Government's equation, made from observations after the change of regimen occurred in 1890 or 1891. Now, is it not obvious that if you apply that equation to the years before the change in regimen occurred, you must correct the St. Clair discharge by the amount of increase of flow in the St. Clair after the years 1889 and '90?

A. The statement does not apply to all of the years; but rather to the total increase in the size of the channel from the earlier period, that is away back to 1883 or before. There was, in all probability, a progressive increase in the size of the channel and its carrying capacity, but if that amount was 24,000, then if one were to deduce the Niagara from the St. Clair discharge, that 24,000, if that is the amount, should be deducted, but I believe the 24,700, as given in the answer to this question, was that the amount was not less than 24,700, and it was afterwards stated that that method was not as precise as another method of obtaining the amount of the enlargement of the channel.

Q. I thought you said the two methods checked?

A. They do.

Q. But it is obvious that there should be some allowance there for that change in regimen, if the change in regimen in fact occurred?

A. There should be, if one were going to try and use those years to deduce the discharge of the Niagara, but that makes one added complication, so that naturally one would not select such years.

Q. Of course the effect of the use of these very high figures in column 5, for the years 1883 to 1890 has been to show that Niagara is very much out of line, whereas if the smaller figures were used, the discrepancy would not have been so great, isn't it?

A. No, I think you are mistaken. It has not been so used, as you will see by reference to other tables and other testimony. For instance in the charts put in today, no years have been used before 1895.

Q. I have not studied these charts put in today; we will have to study them to-night, but I am speaking of Table E, put in in connection with your examination in New York, and from which I understood the conclusion was reached that Niagara was out of line with the St. Clair by—

A. It may clear the matter up if I state that if you look at Table F, the next table, you will note that it is the years 1897 to 1906 that give a difference of 20,700, and as I remember the testimony that was the figures used in deducing the accuracy or inaccuracy of Niagara.

Q. But there was no table prepared in which the entire series of years was used, and in which the years from 1883 to 1890 were corrected by the change in the discharging capacity due to the alleged change in the regimen of the St. Clair?

A. No, because there was no occasion to, those years not being used; those years not being used in deducing the Niagara discharge.

Q. What use did you intend we should make of this Table E?

Mr. Adcock: I think that was explained in the direct testimony.

A. It was not thought that any use should be made of it except this: That Table F, which is supposed to be a more accurate table because it uses the St. Clair discharge by the defendant's equation, was presented as the table which showed the most accurate results, and so that the Government might see what the effect would be of using the St. Clair discharge by the complainant's equation, Table E was introduced. The defendant's equation was considered to be much better because it took into account the rise and fall of Lake St. Clair as well as the rise and fall of Lake Huron.

Mr. Wilkerson: Q. And also because in grouping the observations, there had been a period of a day before included, which was averaged up, or 12 hours included which was averaged up in determining the lake level to which discharge observations were referred. You regarded that as another reason why that was more accurate?

A. These are yearly observations, and there was nothing about a half day or a day in the discharge.

Q. No, I am speaking about the defendant's equation, the St. Clair discharge deduced from the defendant's equation; and the defendant's equation was deduced in the manner testified to in this case, by grouping the observations and weighting them, wasn't it?

A. Not to my knowledge, I believe it was not.

Mr. Williams: The increment used is derived from the group observations.

Mr. Wilkerson: Q. The observations were grouped and

weighted, and they referred to a gauge reading in which they were dated 12 hours back.

A. I will say that I did not recall that, or know it. The defendant's equation, I knew, introduced the element of the height of Lake St. Clair, and it was thought to be better by me on that account.

Q. That was recognized in the complainant's equation too, was it not, by a correction that was made when it was deduced?

A As I remember the Complainant's equation, it was assumed that Lake St. Clair would vary in a definite proportion with Lake Huron; that is no account was taken of the variations of Lake St. Clair from that assumed uniform variation. I am stating this from memory.

Q. Now have you any very definite idea in your mind Mr. Stearns of just why the discharge method that was used by Mr. Williams always got a larger increment than the method used by the Government Engineers from the very beginning in these computations? Did you ever try to figure that out?

A. I have examined the tables that he made and there were various methods, first, as I recall, in regard to the St. Clair increment, it was using mathematical results instead of stretching a thread through the points, and assuming the different observations to have equal weight. That is the most correct way to do it. Then there were other methods tried which seemed to me reasonable and proper, which gave higher results.

Q. You did not study however the manner in which the observations have been grouped?

A. I looked at some of the groups but I did not study the list of observations to see how they had been selected.

Q. You did not study to see whether there had been any method used in grouping?

A. No, except to a limited extent.

Q. As a matter of fact, the difference between this socalled three point method and the stretching of a string, did not make any particular difference, did it? It was slight?

A. It was only three or four per cent.

Q. Very slight. And the fact that the observations were weighted did not make very much difference, did it?

A. I don't recall.

Q. Isn't it a fact that the thing that made the difference was the peculiar way in which the observations had been grouped, and the inclusion of this 12 hour period in deter-

mining the gage reading to which the discharge measurements were referred?

A. I did not recall the 12 hour period and I do not know now whether that is the best one or not for the St. Clair River.

Q. Did you know that in the study which was made of the Niagara River measurements that 65 per cent. of the observations had been rejected or neglected?

A. I do not recall whether I knew it or not.

Q. Now in this Table F, your Exhibit Number 1, I observe in column 2 you have the Niagara discharge as figured by the International Waterways Commission formula?

A. Yes.

Q. That was a formula in which no consideration was given to the observations of 1907 and 1908, was it not?

A. I don't know. I do know, however, that it gives substantially the same results as the equations of the Complainant, as shown on the charts submitted here this afternoon.

Q. And in Table E, you have the St. Clair discharge Complainant's equation. The International Waterways Commission had a figure for the St. Clair discharge too, didn't they?

A. No.

Q. Did it not?

A. No, they used the Detroit River, except on some occasions when there was ice in the stream, and they resorted to the St. Clair. I might have made a mistake in my statement.

Q. I was just directing your attention for the purpose of refreshing your recollection to Table number 23 which appears in the Report of the International Waterways Commission for 1910, page 53, in which there is an increment stated for the St. Clair River at five different elevations.

A. I also note that there is a very elaborate equation for the St. Clair River discharge on page 46, and another for the Detroit River discharge on page 47. When I have referred to the International Waterways Commission's discharge equations, I have referred more directly to their tables as deduced from those discharge equations; and the tables giving the discharge, as I recall it of the Detroit River, and not of the St. Clair, except on rare occasions.

For instance, if you will refer to Table 26, which begins on page 131, you will see at the head of one of the columns there is the inflow from the Detroit River. On page 102, the discharge from Lakes Michigan-Huron is given as the outflow from Michigan-Huron through Detroit River, and at the bot-

tom there is a foot note indicating that discharges marked with a small a, are cases where the St. Clair River discharge was used.

Q. Why didn't they use the St. Clair, the Deep Waterways Commission, if you know?

A. Why didn't the International Waterways Commission use the St. Clair?

Q. Yes?

A. I presume it was because they thought that the other was better, but I don't know.

Adjourned to Thursday, October 16, 1913, 11:00 A. M.

Thursday October 16, 1913, 11:00 A. M.

FREDERIC P. STEARNS, resumed:

Mr. Wilkerson: Q. Do you understand Mr. Stearns that it is a generally recognized principle in making deductions from rainfall and run-off that in times of large rainfall, the percentage of run-off is greater in proportion than it is in times of low rainfall?

A. I think that is true.

Q. That is to say we have a season when there is a very heavy rainfall, and the ground becomes saturated, there will be more water in proportion of run-off than in a dry season when most of the water is absorbed in the ground and very little runs off?

A. Yes.

Q. So that in a year when you have a very heavy rainfall, the percentage of that which would go into the lake would be higher than the percentage of the small rainfall which would go into the lake?

A. That is so as a rule, as shown by the examinations which I have made.

Q. And in this discussion of the relation of rainfall to run-off, by Mr. George W. Rafter of the United States Geological Survey, which I read to you yesterday—

Mr. Adcock: Just a moment, is that an official report?

Mr. Wilkerson: Department of the Interior, United States Geological Survey, is what appears on it. I am not offering it. I am simply asking Mr. Stearns whether he agrees with it.

Mr. Adcock: I don't think you have a right to refer to it

unless it is a report made by an official, in accordance with some duty.

Mr. Wilkerson: Q. I direct your attention to the fact, Mr. Stearns, that Mr. Rafter—who is I assume an expert on this subject, is he not?

A. He was.

Q. Or was at the time. He states with reference to rainfall and run-off:

"Safe deductions cannot be made from an average run-off. What is wanted is a clear statement of the minimum together with the longest period which it may be expected to occupy. There is very serious danger in using percentage. The influence of the May rainfall is such that when above the normal, the stream flow is likely to be maintained during the summer." That is in accordance with your observations, is it?

A. The question was do I agree with that?

Q. Yes?

A. Yes.

Q. And it is also true, is it not, that in years of small rainfall, or at any rate in years when there is a small rainfall from June to November, the evaporation on the lake surface is likely to be higher than in years of large rainfall?

A. I do not think there is a material difference in the amount of evaporation. That is shown by taking experiments which have covered a series of years, and they do not vary much with the amount of rainfall. That is the rain period occupies so small a part of the time that there is still remaining a long period when evaporation takes place.

Q. What I had in mind was in a long hot dry season the evaporation was likely to be more than it would be—

A. In a hot season, the evaporation is more than in a cold season because the temperature of the water is greater, but the question of its being dry or wet is not very material; and I state that as the result of comparisons with the actual amount of evaporation in different years. It is affected somewhat by the amount of rainfall.

Mr. Adcock: You haven't any objection to the record showing that this report was published in 1903?

Mr. Wilkerson: Not the slightest. The report from which I read was published in 1903.

Mr. Adcock: It appears from the report that the tables were made up in 1899, that is the last table that appears, in 1899.

Mr. Wilkerson: I assume it does not make any difference because he said he agreed with what Mr. Rafter said.

Mr. Adcock: There were some other things you read from Mr. Rafter.

Mr. Wilkerson: That was yesterday.

Mr. Adcock: Yes.

Mr. Wilkerson: Q. Now, what is it makes the lake higher one time than another, as you understand it, Mr. Stearns? For instance on your chart number 1, we have lake elevations plotted here for 570 to 574½ feet.

A. I presume you refer to Lake Erie.

Q. Lake Erie, yes.

A. The cause of its being higher in one year than in another is due primarily to the run-off of its drainage area, including in that term the whole drainage area away up to the drainage area of Lake Superior. But it may be affected at times by the storing or withdrawal from storage of the water of the Great Lakes above it.

Q. So that a period of large run-off would indicate a period of high rainfall on the drainage basin?

A. Not necessarily. A high run-off into Lake Erie, because of the time required for the water to come from Lake Superior and Lakes Michigan and Huron into Lake Erie, it would be the effect of high run-off for years preceding the date in question.

Q. Now then in Chart number 1, Stearns' Exhibit number 2, I understand you have plotted the Niagara discharge as you have deduced it from the International Waterways Commission figures as to the St. Lawrence discharge. That is to say you have taken the St. Lawrence discharge for the particular year, and you have applied to that a correction which is obtained by taking into consideration the run-off of the Ontario basin, and by making an allowance for evaporation; and also by taking into consideration the storage?

A. Yes.

Q. Let me direct your attention to the year 1883, which is plotted on this chart. That shows, as I understand it, a mean lake elevation of 573.8. It shows a mean discharge of 277,400 cubic feet for Niagara. That is to say the discharge which corresponds to lake elevation of 573.8 is 277,400 cubic feet per second. Now then if as a matter of fact your tables are in error, in that you have not made a sufficient allowance for the quantity of water which runs into Lake Ontario from the Lake Ontario Drainage basin, you would have to subtract

from your St. Lawrence figure a larger sum than the one which you have subtracted, and the result of that would be that the circle which is plotted under the date 1883 would be shoved over nearer the left-hand side of the chart, would it not?

A. That would be the effect of it, to shove it towards the left hand, and the amount it would shove it on a given assumption, I can tell you.

Q. I want to get the general effect first, that is the effect of making too small an allowance for that one thing would be, if it were plotted correctly, it would be shoved over towards the left?

A. Yes.

Q. And that same thing applies to the other years?

A. Yes.

Q. Now if as a matter of fact for a very low elevation, as for instance where the elevation is 571; take the year 1895 where the elevation is 571.32, if as a matter of fact in making the correction by which you have gone from the St. Lawrence International Waterways Measurement to the Niagara measurements, you have allowed an amount for the run-off into Lake Ontario from the Lake Ontario basin which is more than you should have allowed, the result would be that you would have subtracted from the St. Lawrence figures an amount which is too large, and the effect of that would be that the circle for 1895 on that assumption would be shoved to the right of the chart by an amount which you could determine, referring to your tables, if you knew the amount of the mistake?

Q. If there were a mistake.

Q. Yes, and it were in that direction.

A. And I knew the amount of the mistake, and it was in the direction you have stated, it could be determined.

Mr. Wilkerson: In view of the laugh of the expert on the otherside, I will say it appears from his own figures that there has been a mistake. It appears conclusively from Mr. Williams' statements that there has been a mistake.

Q. Now then you have used, in making the deductions for the Niagara discharge from the St. Lawrence discharge a constant percentage , have you not?

A. Yes.

Q. Of the relation of run-off to rainfall?

A. Yes.

Q. And you have not taken into consideration the fact that

the percentage of run-off where there is a large rainfall is greater than it is where there is a small rainfall?

A. I have not gone into that refinement.

Q. You did not go into that refinement in any of the charts which you have drawn?

A. No. I went into the refinement of determining the percentage for the average conditions at Ontario and for the average conditions at Erie; but I did not think it worth while to consider the differences of different years, but can do so.

Q. I direct your attention to the fact that the discharge measurements for the Niagara river which were introduced in evidence in this case show the following facts with reference to discharge as related to lake elevations:

Take Observation number 84, December 7, 1898, of Lake Erie, level 573.69, the observed discharge 234,500. Now let us take your chart and see what discharge your curve gives for a reading of 573.69.

A. Which chart do you wish?

Q. This one, Chart number 1. I mean your line, your increment.

A. 264,000. That is by the main increment shown on the chart.

Q. It is by the increment which you have deduced from the St. Lawrence discharge?

A. Yes.

Q. Now let us take December 10, Lake elevation 573.92; the observed discharge 240,900. What is the discharge as derived from your increment?

A. 272,000.

Q. Now take September 24, 1898. I am picking these out at random. Lake elevation 572.24; the observed discharge is put down in the Government tables at 206,600. What is it according to your increment?

A. 212,000.

Q. Take October 4, 1898, 571.65; the observed discharge 188,700.

A. 191,000.

Q. 570.64?

A. The date?

Q. The date is October 17, 1898, 169,200. What is yours?

A. 154,500.

Q. 570.03; the observed discharge 154,500. What is it according to your curve?

A. 132,500.

Q. Now Mr. Stearns I ask you to give consideration to the figures which have been put down here, and which have been taken at random from the Niagara measurements, to get the fact that for an elevation of 573.69, which is a comparatively high elevation, your computed discharge is almost 30,000 cubic feet per second in excess of the observed discharge; that for an elevation of 571.65 it is practically on the line where the line of your increment crosses the line of the Government's increment, the difference is 2,300 cubic feet per second, your deduced discharge measurement being greater by that amount than the Government's discharge measurement. For an elevation of 570.3, your deduced discharge measurement is 22,000 cubic feet per second less than the Government's observed discharge measurement. I ask you what in your opinion there is in the construction of the current meter which would cause it to register 30,000 cubic feet less, which would cause it to under-register 30,000 cubic feet in the one instance, to register pretty nearly accurately in the other, and to over-register 20,000 cubic feet in another?

A. In regard to the last statement about 20,000 feet, the point is far beyond the limits of the data on which the comparisons have been made. But aside from that, I do not know of any reason why the current meter should register such differences.

Q. That would not indicate to your mind that in these sections which were measured by the Government Engineers this current meter was uniformly under-registering?

A. No.

Q. Because it is obvious that it was under-registering in one case and over-registering in another, assuming your equation is correct?

A. I do not think it is obvious. There are many elements that enter into the measurement of discharge, in addition to the revolutions of the current meter.

Q. Well, anything that would have a constant effect, and with reference to which the errors would not be largely compensating?

A. I don't know as to that. I could not grasp all of the features that entered into those measurements.

Q. What I want to do is this: We are trying to get the truth in this case. You have drawn a curve here, in which you have deduced a figure of 35,600 cubic feet per second from the Niagara river; and you have done that, not by taking observations at Niagara, but by taking the observations at the

St. Lawrence and reducing those according to your process; so that you have got your Niagara measurements from the measurements of the St. Lawrence?

A. Yes.

Q. It appears now that the discharge measurements which you have deduced are at one lake stage very much higher than those recorded by the Government engineers, while at another lake stage they are very much under those. Would it not seem to you that there was more probability that you have made a mistake in not handling this run-off in a proper way either in getting the percentage of run-off, or in not judging the percentage of run-off to rainfall than it is that these current meter Government measurements should be that much off?

A. To take the whole situation, there is a dilemma, in that there are measurements at Niagara that are consistent in themselves and seem to give, as one observes them, good results. There are measurements at St. Lawrence and at the St. Clair river, which are also consistent and seem to give good results.

If one were taking measurements at two points on the St. Lawrence river, or were taking measurements on the St. Clair and Detroit rivers, they would know that a large discrepancy could not be accounted for by the rainfall and run-off between the two. It would obviously be a difference in results, as for instance, at two points on the Niagara river.

Now in the method that has been followed in deducing the Niagara discharge from the St. Lawrence and St. Clair discharges, there are comparatively small quantities of run-off and evaporation; that is they are comparatively small in relation to the whole flow of the river. And it has been found by examination that any allowance for evaporation and run-off which is at all reasonable will still show that the Niagara discharges are in error in the manner shown by the diagrams.

To take the two years referred to in the earlier questions about the observations of 1883 and 1895, the correction applied for the evaporation and the run-off into Lake Ontario amounted to 12,110 cubic feet per second; the run-off itself amounting to 15,100 cubic feet per second. If the run-off had been twice as great as estimated, which I believe to be an entirely impossible condition, the difference would have been reduced by 15,000 cubic feet per second still leaving an error of 22,600 cubic feet per second. This is the year when the rainfall was 1 inch less than the average on Lake Ontario, and if I nad taken into account the smaller run-off due to the lower rainfall, the run-off would have been less than 15,100 cubic feet per second, which would make the differ-

ence still greater than the 37,700 shown by the table and diagram. If there is an error in making the run-off too large, it obviously would increase the discrepancy.

If we take the other year mentioned, 1895, the correction for the evaporation and run-off is 6,410 cubic feet per second. The correction for run-off is 12,680. If this had been doubled, the deduced discharge would have been reduced by 12,680, giving as a result 156,620, cubic feet per second as the deduced discharge of Niagara. This would have shown, I believe, without computing, practically the same increment as if these changes had not been made.

Q. How about the rainfall in 1895?

A. I was going to call attention to that. The rainfall in 1895 was only 15.93 inches. It was one of the lowest years in the tables, which cover 24 years. And the actual run-off with such a low rainfall would, if I had gone into refinements, have been shown to be much less than the 12,680; so it is inconceivable, I believe that with that low rainfall, the percentage of run-off could have been greater than shown in these tables. The corresponding deductions from St. Clair agree very closely as to the increment, and I think also as to the quantity, with the deduction from the St. Lawrence.

Mr. Wilkerson: I move to strike that out. That is not a competent answer to the question.

Q. Did you, in deducing the Niagara discharge from the St. Lawrence measurements take into consideration any change of regimen in the St. Lawrence river?

A. Yes.

Q. What ones did you consider?

A. The change due to the building of the Gut Dam. In chart number 1, I assumed that that being a matter of knowledge to the International Waterways Commission, they had taken that into account in their printed figures, it being such an important factor. And in chart number 2, where the United States Lake Survey equations of 1912, were used, a different equation was used for the years from 1904 to 1906, inclusive, from that used in previous years.

Q. You prepared no diagram which shows the difference between your increment and that of the Government engineers, based upon the United States Lake Survey Report for 1912, as to the St. Lawrence river outflow, did you?

A. No, I used the Government's equation which included their increment, but made no comparison with it. Possibly I don't understand the question.

Q. On this chart 1 of yours, Mr. Stearns, let us take the

year 1890, for instance, and see what the effect would be there if there had been an insufficient allowance for run-off.

A. The run-off in that year was 20,900 cubic feet per second, and any addition to that amount would decrease the deduced discharge at Niagara by the amount of the addition.

Q. How, much of a correction would there be for that on the same basis that you spoke about the year 1883?

A. If the amount of run-off were twice as great as is shown, it would reduce the deduced discharge from 249,000 to 228,600.

Q. Which is substantially what it was by the International Waterways Commission?

A. Yes, only 3,000 cubic feet per second more.

Q. Now, let us take the year 1892 and see what the effect of that would be, making a correction.

A. The correction for run-off in that year was 18,450 seconds feet; an error of 100 per cent., doubling the per cent. of run-off, would diminish the deduced discharge from 222,-400 to 203,950 cubic feet per second.

Q. That would put it away over to the left of the Government's line?

A. Yes. It may be well to say as applying to all of the four years that have been referred to that in any given year the amount of run-off due to a given amount of rainfall in six months depends to a considerable extent upon the way in which the rain comes. If it comes in heavy rains, more will run off and less will be evaporated than if it comes from time to time in small showers through a month, giving the same total but the averages of a series of years show a large degree of uniformity.

Q. But the point that I think now is obvious, is it not, is that if the allowances which are made for run-off in this computation be changed, that is, if the percentage be changed, the corresponding discharge measurements will be changed, and the whole line will necessarily be changed?

A. It will be set back, but not necessarily changing the increment.

Q. It might not necessarily change the increment and it might?

A. Presumably it would not, because the conditions of run-off and evaporation vary with rainfall and not with the elevation of the lake, and the differences there clearly vary with the elevation of the lake.

Q. As a rule, doesn't the elevation of the lake follow the rainfall, over a series of years?

A. No. As showing that, I plotted the local supply of lakes St. Cair and Erie, that is combining the run-off and the rainfall in connection with the elevation of the lake, and there is no indication that the rainfall is more when the lake is high than when it is low. The results are quite variable, as might be expected.

Q. Where does the water come from if over a series of years you have high lake levels, doesn't it necessarily mean a high rainfall?

A. It means that there is high rainfall preceding on all of the lakes, or some part of the lakes from Ontario to Superior. A high lake level is the result of that rainfall in previous years.

Q. It may be because of my stupidity, but I still cannot see why if following this method that you have followed here, if you take the run-off to be just twice what you have assumed it to be right through, if some years when you have a low run-off you multiply that low figure by two, and some years when you have a very high run-off you multiply that figure by two, and you combine those with other discharge figures, I cannot see why the effect of that is not to change the whole line, without regard to whether it makes it greater or less, I can't see why the introduction of a change of that kind would not change the increment. I don't undertake to say where it would throw it; it seems to me it would change the line.

A. It changes the location of the line, but not the increment. But it must be remembered all these changes of 100 per cent. are wholly hypothetical and assumptions entirely out of accordance with the facts as shown by a multitude of observations.

Q. Just as the one which you applied, as we think, compared with Mr. Williams' figures. You have had some experience in stream measurement, have you Mr. Stearns?

A. Yes.

Q. What kind of streams?

A. Small ones generally.

Q. You used the current meter?

A. Yes.

Q. And got accurate results as you regarded it?

A. Yes.

Q. What was the discharge of the largest stream in the measurement of which you took part, at the time of the measurement?

A. I can explain in one way: It has always been so small that I could use a current meter on the end of a rod, so that

I could hold it in its position that way; that is, the streams were three or four or five feet deep generally.

Q. Do you remember the discharge approximately in cubic feet per second?

A. Why, the average discharge of the Sudbury river, which is one of the streams I have in mind, was about 120 cubic feet per second.

I remember once measuring a larger stream in Michigan, but that was only for a day or two and was still within the depths where I could use a current meter on a rod.

Q. You have had your attention directed have you not, Mr. Stearns to the third section which was measured on the Niagara river?

A. Yes.

Q. Have you given any consideration to that at all?

A. No, I saw a chart showing the lines, and a blueprint, with typewriting matter.

Q. You are not prepared to say whether or not a consideration of that might lead you to modify some of the facts which you have expressed with reference to the correctness of those Niagara discharge measurements?

A. I am not.

Q. Would the fact that the measurements in that section checked very closely with the measurements in the two sections which have already been referred to in evidence be an indication to your mind that there was a stronger reason than there had been to believe that the Niagara measurements were correct?

A. It would have some weight because it would give some further evidence that the incorrectness was in the gagings of the St. Clair and St. Lawrence. But there is an absolute inconsistency which cannot be reconciled in any reasonable way in the Niagara gagings and those of the St. Lawrence and St. Clair. It would have some weight though, I think, if they were sufficiently extended and proved to be right as far as could be judged, in saying which were correct.

Q. When you say "inconsistency," you mean inconsistency on the basis of the run-off as you have computed it, and other factors that you have indicated?

A. Yes, as I have indicated and as I conceive that it could be. I cannot conceive that the run-off, for instance, at high levels of the lake with the same rainfall is going to vary from the run-off at low levels of the lake with the same rainfall, and applying any amount of run-off, assuming it to be in propor-

tion to the rainfall, will still give that inconsistency in increment for the Niagara discharge.

Q. But you saw the table prepared here for certain years, in which the Niagara and St. Lawrence checked very closely, did you not? I think that was our Exhibit N.

A. As to the actual quantity by the computations which have been made, they do agree in some years, but the increment does not.

Mr. Wilkerson: That is all.

Adjourned subject to notice.